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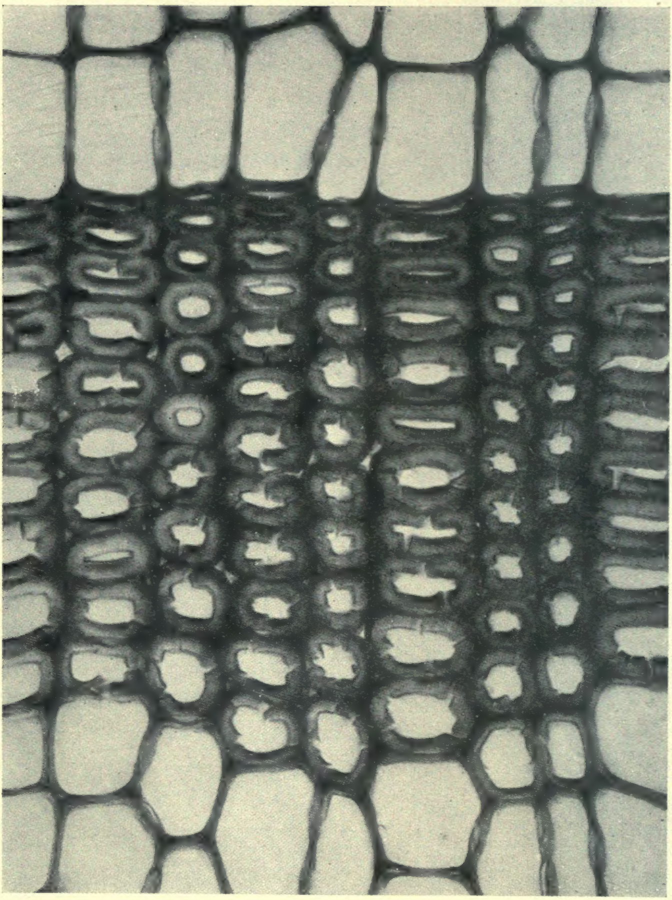
BUILDING MATERIALS



Cross section of the wood of Western Larch, showing fissures in the thick-walled cells of the late wood due to drying (*Mechanical Properties of Wood*, by S. J. Record). See page 144.

[*Frontispiece.*

BUILDING MATERIALS

BEING AN INTRODUCTION TO THE STUDY OF THE PRINCIPAL MATERIALS USED IN BUILDING CONSTRUCTION

BY

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PREFACE

THIS book is intended to be an introduction to the study of Building Materials for the instruction of the young builder and architect.

Only the principal materials are dealt with, special stress being laid on the exact examination of the materials for their constructional strength under different conditions, and their composition as revealed by chemical analysis, and by the microscope.

The author realises that some, at any rate, of his readers may be unacquainted with the elements of chemistry. He has, therefore, tried to make the essential chemical information as simple as possible at the risk of some repetition.

The student is advised to regard this book as merely introductory, and pursue his studies further by reading, more especially, Howe's *Geology of Building Stones; The Materials of Construction*, by Johnson; *The Chemistry and Testing of Cements*, by Desch; *Concrete, Plain and Reinforced*, by Taylor and Thompson; *Modern Brickmaking*, by Searle; *The Mechanical Properties of Wood*, by Record; *House Painting and Decoration*, by Jennings; and *Modern Asphalt Pavements*, by Richardson.

The author wishes at this point to express his deep indebtedness to these text-books in particular, as well as to others, for the information contained in the following pages.

In addition, various text-books, the publications of the Engineering and Architectural Societies, both here and in America, and the Reports of the Washington Bureau for the investigation of Building Materials have been consulted.

Students interested in the resistance to fire of various materials should consult the Reports of the Department of Scientific and Industrial Research.

The author wishes especially to thank Professor Desch, Mr Searle, Mr Howe, Mr Borthwick, Mr Jennings, and Mr Vaughan for having kindly looked through the chapters in which they are specially interested, and made many valuable criticisms and suggestions.

A. P. LAURIE.

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ERRATUM

Page 75, line 12:—

for $\frac{1{\cdot}55}{C+S+G}$, and of gravel, $\frac{1{\cdot}55}{C+S+G}$

read $S\frac{1{\cdot}55}{C+S+G}$, and of gravel, $G\frac{1{\cdot}55}{C+S+G}$

BUILDING MATERIALS

CHAPTER I

BUILDING STONES AND THEIR DISTRIBUTION

In order to have an intelligent understanding of the properties of building stones, it is necessary to know something of their composition and mode of formation.

If a piece of sandstone, of limestone, and of granite be examined side by side, it is evident that they differ widely in the materials of which they are composed, and therefore may be expected to behave quite differently when used for building purposes. In order to perceive to what these differences are due, it is necessary to study their structure and know something of their history. A walk along a sea-beach or the bed of a mountain stream and an examination of what is to be found there, will enable us to understand something of the history of the fragments of stone we have been examining.

At one place on the beach we shall find gravel, at another sand, at another heaps of broken shells, and at another deposits of fine mud. If we next visit a quarry, or examine a cliff or the rocky sides of the gully of a stream, we shall quickly realise that the hard stone of the rock is of similar materials to those of the sea-beach, merely compacted and cemented together into a solid mass. The rock will be found to be lying in layers or "beds," one above the other, and if an exposed layer of sandstone be examined, the ripple marks that we have seen on the sea-shore may be recognised; and if a piece of limestone be broken off it will in many cases be found full of the fragments of shells. In another place, a conglomerate, an old gravel composed of sand and pebbles, and in another place a shale composed of fine mud will be found. We have, therefore, already gained some conception of the story of the sedimentary rocks which have evidently in the past been deposited in rivers, lakes, and on the sea-shore.

If we now proceed to a more careful examination of the pebbles piled up on the beach or the mountain stream, we shall find that many of them consist themselves of fragments of sandstone and limestone, brought down by the stream from the mountains in the interior, fragments formed from detritus which once was washed down from earlier mountain ranges. We begin to get a dim conception of the vast repetitions through many millions of years of the same processes—the slow elevation of a land above the surface of the sea—the immediate assault on the exposed surface, by wind, rain, and frost—the disintegrating and dissolving of the surface and washing of the remnants into the sea—the slow cementing and compacting together of the detritus, which again in its turn will be lifted above the ocean-bed to undergo fresh denudation.

Sandstone and Limestone

We have found upon the beach the beginnings of the two great groups of sedimentary rocks, the sandstones and the limestones, and we must now examine them both a little more closely. It is evident that the two kinds of stone differ very much in their origin. The sandstone is compacted of the accumulation of the detritus washed down by the streams, while the limestone is compacted of the remains of the skeletons and shells of secreting molluscs, and other living dwellers in sea and lakes, homes which the living inhabitant had built in solid form from material dissolved in the sea or lake water.

In addition, a simple experiment will show that the material of which sandstone and limestone are composed differ very materially.

Action of Acids on Sandstones and Limestones.—If a strong acid, such as hydrochloric acid, be poured on some fragments of each, the limestone will rapidly dissolve with a brisk effervescence, due to the evolution of a gas, while the sandstone will show only a slight effervescence or none at all. If the test is pushed further by selecting different samples of sandstone and immersing them for some time in hydrochloric acid, some will remain unchanged, while others will ultimately disintegrate into a loose heap of sand. Clean sea sand treated with the acid will be found not to dissolve, and beyond a slight coloration of the acid, in some cases, or a slight effervescence due to fragments of shell, no change will take place.

It is evident then, that sandstone and limestone not only differ in origin but are composed of quite different substances. The **limestone** consists of a substance readily soluble in strong acid. The **sandstone** consists of grains of sand insoluble in hydrochloric acid, and which are left as a residue even when the sandstone is disintegrated by the acid.

If the results of treating different sandstones with the acid be considered, it is evident that all the sandstones consist of grains of sand cemented together, but that the cementing material is not the same in every case. In some cases, the cementing material is soluble in the acid, so that the whole structure of the sandstone fell to pieces. In other cases, the cementing material is insoluble in the acid and the stone remains unchanged. We shall have to consider these facts about sandstone in more detail presently. In the meantime we shall take up a more exhaustive examination of limestone.

Limestone (Chalk, Marble).—Having briefly pointed out the obvious distinctions between limestone and sandstone, we will now proceed to consider the nature and varieties of limestone in more detail. We have seen that limestone dissolves in strong acids with effervescence, due to the evolution of a gas. If we try the same experiment with chalk and marble, they will behave in the same way. This is due to the fact that all three are composed of the same substance known as calcium carbonate or carbonate of lime. As this is the first example we have had of chemical nomenclature, a few words of explanation are here appropriate. The use of the word "lime" requires no explanation, as we are all aware that by heating limestone, chalk, or marble, the substance left in the kiln is known as quicklime. It remains, therefore, to explain what we mean by "carbonate of lime."

As we have seen, when treated with acid, the limestone dissolves with evolution of a gas. This gas was called "fixed air" by Black in his classical researches, and was identified as being the same gas which is produced by the combustion of charcoal (that is, the combination of charcoal with the oxygen of the air).

Charcoal was found to be only one variety of an elementary substance (the diamond is another variety of the same substance) to which the name carbon, from the French *charbon*, was given.

The gas having certain acid properties was called "carbonic acid gas," and its compound with lime carbonate of lime.

The other name for carbonate of lime requires us to probe a little further into its constitution.

Sir Humphrey Davy by the use of powerful electric currents succeeded in isolating from substances prepared from lime, a new metal, soft, white, and easily oxidised in the air, to which the name "calcium" was given, from the Latin *calx*.

The oxide of this metal, quicklime, combines with carbonic acid gas, and the compound is called calcium carbonate. Chemical nomenclature is therefore designed to express the composition, and the story of the formation of a substance. At first formidable in appearance, they are of the utmost convenience when once the principles on which they are built up are understood.

This substance, calcium carbonate, is found in nature crystallised in two forms, these two minerals being known as calcite and aragonite. Calcite is the commonest form in which it crystallises, and if a thin piece of a sea-shell is cemented on to glass with Canada balsam, and then ground down until it is sufficiently thin to allow light to pass through it, and examined under the microscope, it is found in most cases to consist of microscopic crystals of calcite.

Origin of Limestones.—As might be supposed from their origin, limestones are found to consist of many different varieties of marine and fresh-water remains of organisms that have formed protecting coatings for themselves of carbonate of lime, many of them being microscopic shell remains which have been deposited in countless myriads on the ocean-floor.

It is only necessary for us to mention some of the more important groups of these remains of which limestone and chalk are composed.

We find among others—

1. **Shell Limestone**, many of which are formed from the shells of salt-water or fresh-water mollusca. The limestones derived from mollusca are again divided into groups according to the mode of life

of the mollusca of which they are composed. Examples of these are to be found in certain beds of Portland and of Purbeck stone. The shell beds in the Portland quarries contain the fragments of a sea-water mollusc (*Cerithium Portlandicum*), the shell beds of the Purbeck series are the fragments of a fresh-water mollusc (*Paludina*) and fresh-water mussels. In addition many limestones are largely composed of the shells of Brachiopoda.

2. **Crinoidal Limestones.** — Other limestones are formed principally of the remains of Crinoidea or sea-lilies (*Echinoderma*). Many examples of these limestones are to be found in the Carboniferous series, such as Bird's-eye marble.

3. **Foraminiferal Limestone.** — Chalk consists of the shells of the microscopic Foraminifera (*Protozoa*). They are also found very widely distributed through other formations and the calcareous ooze at the bottom of the bed is very largely made up of these minute organisms.

4. **Coral Limestones.** — In warmer oceans the coral limestones are being built up to-day. Many of the limestones of the Carboniferous and Devonian series consist of coral.

5. **Bryozoa.**—Certain limestones are composed of the calcareous remains of the Bryozoa, whose fossils resemble the small-celled corals; more especially they are common in some magnesium limestones or dolomites. Closely allied to lime in its properties is the oxide of the metal of magnesium, which is known as magnesia, and like lime it combines with carbonic acid gas to form magnesium carbonate.

A mixture of magnesium and calcium carbonate thus gives rise to the series of rocks known as magnesian limestones. The most magnificent example of these rocks are the dolomites of the Tyrol. There is a well-known outcrop of magnesian limestone running due north and south through Yorkshire and Durham, and in many places it has been used as a building stone.

The Mansfield stone is obtained from this outcrop, and a magnesian limestone was largely used in building the House of Commons.

The Weathering of Limestone.—The behaviour of this stone when weathering is of great interest, and requires some explanation.

We have already observed that if limestone is treated with a strong acid, like hydrochloric acid, it dissolves with effervescence, giving off a gas known as carbonic acid gas, which was identified by Black in his chemical researches on "Fixed Air" as being the same as the gas produced in the complete combustion of charcoal, by the combination of the charcoal (carbon) with the oxygen of the air.

This gas is always present in the air in small quantities and is slightly soluble in water. If some moist, freshly prepared carbonate of lime is shaken up with a solution of this gas in water it is dissolved, forming a solution which is known as calcium bicarbonate.

This is one of the ways in which the weathering of limestones takes place, the carbonic acid gas, dissolved in the rain water dissolving the actual substance of the stone.

Oolitic Limestones. — As has already been explained, most limestones are derived from marine or fresh-water deposits of shells.

In some areas there are large deposits of limestone rock, made up of rounded grains like the roe of a fish. Such limestones are called oolitic limestones. The main examples of such limestone in this country are to be found in the Bath and Portland stone series of beds belonging to the Jurassic system. When examined under a low power microscope, the rounded grains are seen with spaces between, cemented together by calcite.

The oolitic limestones differ considerably in their weather resisting properties. This is apparently due to the condition of the crystals of calcite, well-formed crystals resisting weathering test. The Bath stone weathers badly, while the Whitbed of the Portland quarries weathers remarkably well, resisting even the London climate.

Travertine.—There is another kind of limestone which we have not yet considered, which has been deposited from water, and is known as travertine.

An example of a water-deposited limestone is to be found in the stalactites and stalagmites of a limestone cave. If the stalactite is still growing, water will be seen oozing down the sides and dripping from the end. The water, charged with carbonic acid gas, is dripping down from the limestone formation above, with calcium carbonate in solution, in the form of bicarbonate. Partly owing to the decomposition of the bicarbonate and the escape of the carbonic acid gas from exposure in thin layers to the air, and partly from evaporation of the water, the limestone is deposited. Deposits of travertine are not of importance in this country.

Marble, which is composed of calcium carbonate, will be discussed later.

Sandstones

The experiment with hydrochloric acid showed us clearly that the cementing material in sandstone may differ in different sandstones.

When we remember the origin of sandstones and the complex nature of the materials from which they have been formed, we should expect that both the grains and the cementing material will vary.

As an actual fact, pure sandstones consist, as far as the grains are concerned, principally of quartz, simply because quartz is very hard and very insoluble, and therefore survives.

There is much more variation in the cementing material. Sandstones may be roughly classified into certain groups according to the nature of this cementing material.

1. Sandstones in which the grains are cemented with silica. This silica has probably been deposited from solution, possibly in some cases by the partial solution of the quartz grains, in other cases by changes taking place in an original clay cement. The classical example of such a stone is the Craigleith stone formerly quarried near Edinburgh. This is the most durable sandstone known.

2. Sandstones cemented together by fragments of felspar. These are fairly durable stones.

3. Sandstones cemented together by calcite, and passing through every gradation from sandstone with a small amount of calcareous cement to calcareous sandstones and from calcareous sandstones to sandy limestones. Such stones are not so durable as the others already described.

4. Sandstones cemented by clay, or compounds of iron. These are the least durable of all.

Besides quartz, sandstones often contain sparkling fragments of mica and small quantities of other minerals. By cutting a stone into thin slices and examining under a polarising microscope it is possible to identify the minerals binding the fragments of quartz together and study the nature and arrangement of the cementing material. In this way valuable information can be obtained as to the probable weathering properties of the stone. If there is any doubt about the weathering qualities of a sandstone it should be examined by an expert mineralogist to determine the nature of the binding material.

Also buildings erected with the stone should be examined, looking carefully for weathering at the traces of tool marks.

Granite and the Igneous Rocks

In the opening remarks, three types of stone were mentioned, namely, sandstone, limestone, and granite. Further consideration will have to be given to both sandstone and limestone, but before doing so it is necessary to devote some study to the nature and properties of igneous rocks.

Igneous Rocks. — Some insight into the history of the formation of sandstone and limestone has been obtained by a study of present conditions on the sea-beach. Nothing has been learnt about the history of the formation of granite.

On looking carefully at a piece of granite it is evident that it is composed of several different substances closely compacted together, and the smooth glassy surfaces and bright glittering points reveal these substances to be in the form of crystals.

We are familiar with crystalline forms in many common substances. For instance, both sugar and salt are familiar examples of crystalline substances. If sugar be examined through a lens, the sharp edges, and planes and angles of the crystals of which it is composed are easily seen, but owing to the crushing of some crystals, and the sticking together of others, a perfect and complete crystal is difficult to find.

Ordinary table salt consists of minute crystals, and requires therefore to be examined under a more powerful lens. The crystals of kitchen salt are larger and more obvious. In order to obtain more perfectly formed crystals it is necessary to arrange for their formation under the best possible conditions so as to get perfect specimens. For this purpose solutions of different salts, such as alum, copper sulphate, and cadmium sulphate, should be prepared and allowed to evaporate slowly in the air. It will be obvious on examining the crystals so obtained, that they have been formed according to a certain geometric design and that these designs differ for the crystals of different substances, but that all the crystals formed from one substance belong to the same system.

The simplest possible geometric design is the cube, and many substances crystallise in cubes. Taking the cube as a fundamental design, it is evident that many varieties can be obtained by slicing off the corners and edges more or less, the cube still remaining the original of basic form. All crystals therefore derived from the cube are classified in one group and are said to belong to the isometric system.

In the same way the hexagon, of which the most common example is the hexagonal cell of the honeycomb, is the geometric design for another group of crystals in which variations can be made by slicing off the edges and corners.

In all there are six systems of crystals to one or other of which every crystal may be assigned, namely, the isometric, tetragonal, hexagonal, rhombohedral, orthorhombic, monoclinic, and triclinic systems.

The careful examination, therefore, of different minerals in order to determine to which system they belong is of great importance in their identification. The methods employed in doing this are of marked beauty and ingenuity, and well worthy of study. It is beyond our province to discuss them here.

Sometimes the same substance is found to crystallise in more than one form, such as carbonate of lime, which crystallises as calcite (rhombohedral) and aragonite (orthorhombic) but these two forms are quite well defined and easily recognised.

Crystallisation resulting from Fusion.—To return to the consideration of an igneous rock, crystals can be formed, as we have seen, by deposition of the substance from solution, such as a solution of salt in water, and many minerals have doubtless been so formed, but they can be obtained in another way by fusing the substance and allowing it to cool slowly. While it is impossible to reproduce a piece of granite in the laboratory, a study of the phenomena exhibited by volcanoes, and experiments on the fusion of substances at high temperatures enable us to understand how it has been formed.

The stream of lava flowing from a volcano consists of rock in a state of fusion, and if it is rapidly cooled a glassy mass is obtained, just as in the glass furnace, in which the fusion together of soda, lime, and sand, produces a glass. But if the lava is cooled slowly and then broken and examined, it is found to consist of an aggregation of crystals of different minerals still surrounded by a glassy magma, and the slower the cooling the larger the crystals and the smaller the glassy residue.

Granite is believed to have been formed by the intrusion of masses of fused rock deep down below the earth's surface, where the liquid mass has crystallised, but the actual conditions under which it has been formed are still a subject of discussion.

The two principal crystalline minerals composing granite, are known as felspar and quartz, usually accompanied by mica, and sometimes by hornblende or augite. Quartz has already been brought to our notice as forming the bricks of which sandstone is composed.

Felspar.—In order to understand the composition of felspar a short digression is necessary. Most of us are more or less familiar with the conception of an acid.

Acids and Bases.—Vinegar was the first acid known, and the sour taste of vinegar is common to many acids. If a solution of the lichen litmus, which is purple in colour, is added to vinegar it turns pink in colour. If caustic soda is added to an acid it dissolves and combines, and if just the right quantity is added to neutralise the acid, the litmus solution on being added does not change in colour. A slight excess of soda turns the litmus blue. If the solution after neutralisation is evaporated, crystals are obtained composed of soda and the acid of vinegar (acetic acid) known as acetate of soda, this substance is an example of the class of bodies known as salts. Acids combine with metallic oxides (bases) to form salts. Metallic oxides are formed by the combination of metals with the oxygen of the air, such as the rust of iron or the white powder formed by burning zinc.

Besides the metals with which we are familiar because they are used in the arts, such as gold, silver, copper, zinc, lead, iron, and aluminium, there are many other metals known to chemists whose compounds are quite familiar, although the metals are only known in the laboratories.

To take an example, already given, quicklime is the oxide of a metal calcium, which is prepared and used in the laboratory, and consequently quicklime is called by the chemist calcium oxide.

Silica, the crystalline form of which is called quartz, is a very weak acid at ordinary temperatures even when freshly prepared and moist, but at high temperatures it is a powerful acid capable of combining with metallic oxides to form silicates. The most important of the silicates in the composition of the earth's crust are the silicates of alumina. Silica at a white heat can also combine with soda and lime and other metallic oxides, such as oxide of iron. Glass is composed of such silicates. The silicates met with in nature usually contain more than one metallic oxide, and according to the oxides present and the proportions of the various constituents crystallise as different minerals.

Felspar is an example of such a mineral. It always contains alumina and silica, but may contain in addition potash, or soda, or lime, or mixtures of these.

One of the commonest varieties of the felspars are the potash felspars, known as orthoclase. As potash is a valuable artificial manure, processes have been tried for extracting the potash from orthoclase, and converting the residue by heating with lime into a white cement. Orthoclase felspar crystallises in the monoclinic system.

Another group of felspars, the soda and lime felspars, are known as the plagioclase felspars, and crystallise in the anorthic system. The soda felspars are called albite, and the lime felspars anorthite. Other felspars containing mixtures of these bases have been identified and named.

Weathering of Granite.—The effect of weathering on granite is of much interest. The felspars are attacked by exposure, the potash or soda dissolving and leaving behind a hydrated silicate of alumina, which is known as china-clay.

The quartz crystals, and to a large extent the mica, remain unaltered.

China Clay.—The quarries from which china clay is obtained consist of the decomposed masses of certain granites. The whole mass is washed down with water, the coarse particles of quartz and mica settling first, and the water, still carrying the china clay, running into settling ponds, from which the china clay is removed from time to time. While clays are of various origin and composition, china clay may be regarded as a representative example of a clay, both in its composition and in its leading physical properties.

While granite is one of the most durable of building stones, it sometimes weathers badly owing to partial decomposition of the felspars having set in. In doubtful cases it should therefore be examined microscopically by an expert mineralogist.

Granites are worked in the West of England, Worcestershire and Leicestershire, and Shap Fell; and in Scotland in the neighbourhood of Peterhead and Aberdeen, and in Kincardineshire and Kirkcudbrightshire.

Syenites.—Closely allied to the granites are the syenites, of which Norwegian Labrador and Nordmarkite, which have been largely employed as a building stone in Norway, are examples. In syenites the quartz is absent and they are consequently more easily worked than granite, but they are quite as tough.

Grouping of Igneous Rocks.—It will easily be understood that there are an infinite variety of "igneous" rocks, that is, rocks that have been in a state of fusion, depending on the original composition of the fused mass, the mode of origin, the conditions of cooling, and so on. For instance, a rapidly cooled mass will not only consist of smaller crystals than a slowly cooled mass, but also different minerals may separate from the magma under these different conditions.

While, therefore, igneous rocks are of an infinite variety, they may be classified into certain large groups of which again there are subgroups, according to their mode of origin, general structure, and the minerals they contain. In the first place their mode of origin enables us to classify them into three large groups with distinctive properties.

Tuffa.—While a volcano is active it sends up from time to time immense clouds of "volcanic ashes," as they are termed. In reality these "ashes" are not the same as the ashes of a coal fire. They are tiny particles of the fused rock blown to atoms by the explosive escape of steam contained in the fused rock. Active volcanic action is always associated with the presence of water, which deep down in the melted mass is present in the form of steam under enormous pressure and temperatures. As the fused rock moves upwards in the volcanic pipe this steam escapes with explosive violence, shattering the fused rock into minute particles, which when deposited in masses are called volcanic tuffa. In certain parts of the world where they are sufficiently compact they have been used as building stones; but they are of more interest to the builder because among them are found valuable natural cements, such as the Pozzuolana of Rome and Naples, used by the Romans in Italy to make Roman cement, and the deposits known as Trass on the Rhine and Santorin, and the deposits in Southern France. All these tuffs have hydraulic properties, and must be considered more fully later on in the chapters dealing with cement.

Lava.—In addition to the "ashes" and steam, the volcano pours forth from time to time streams of lava, which cool and solidify.

Old lavas have been classified into different groups according to their composition, namely, rhyolites, trachytes, phonolites, andesites, and basalts.

Pumice.—In certain cases the old lavas are light and porous and are then known as pumice. The pumice deposits in the rhyolite group have been used for building domes. Pumice on account of its properties makes an excellent aggregate with cement, both light and strong.

Basalts.—The most important group of the old lavas are the basalts. They are principally quarried for macadam, but also make an excellent rough building stone.

Third Group. Intrusive Rocks.—The third type of volcanic rocks are the intrusive rocks of which granite and syenite are examples. These rocks have cooled slowly deep down in the earth's crust.

Other representatives of this group are the diorites usually quarried for road metal, gabbro, also a plutonic rock like granite, and found associated with granite masses, and porphyry, and quartz porphyry known in Cornwall and Devon as elvan. Porphyry is capable in many cases of taking a high polish, and was largely quarried in the Nile valley during the Roman Empire. In addition there are the porphyrites which also take a fine polish, such as the "lambay porphyry" found near Dublin. The dolerites and diabase rocks are principally used for road metal.

Metamorphic Rocks.—We have so far considered two types of rock, those produced by fusion and those produced by deposition.

There is yet a third type of rock to be considered. These are rocks which may be either of a sedimentary or igneous origin, and which have since their original formation been subjected to heat and pressure and movement without actual fusion. Such rocks have lost many of their original characteristics and obtained new properties. The mica-schists found in so many parts of the Highlands of Scotland are examples of such metamorphic rocks. The two kinds of metamorphic rocks of most interest to the builder are the slates and the marbles. Slates may be either of sedimentary origin, being formed from converted shale, or of igneous origin. If examined their behaviour is quite different to that of sedimentary shales. For example, shales can be split into thin sheets along the lines of bedding, but are quite easily broken across the lines of bedding; while slates split into thin plates along lines of cleavage which have no relation to the original lines of bedding, and resist being broken across the lines of cleavage.

In the case of slates the original lines of bedding have disappeared, or are only indicated by coloured streaks, and new lines of cleavage have developed, set up by the compression and shearing stresses to which they have been subjected within the earth's crust; generally speaking, the lines of cleavage run at a high angle to the true dip of the rock.

The microscopic examination of slate reveals the presence of many minerals of which the most important are muscovite (sericite), chlorite, and quartz.

True slates can at once be identified by the examination under the microscope of a thin section taken at right angles to the cleavage. The minerals are seen lying in thin streaks in one direction with a felted appearance. This arrangement of minerals is due to the pressure and shearing to which the slate has been exposed. A true slate when examined in thin slices under the polarising microscope should prove to be completely crystalline, and should be rejected for roofing purposes if it is not in this condition.

In this country the slates are found in the oldest formations, namely, the Cambrian and Silurian, and Ordovician and Devonian, and are obtained from Wales, Cumberland, Cornwall, and the Western Highlands of Scotland.

Marbles.—The true marbles are limestones which owing to metamorphism have been recrystallised and lost all traces of their original structure. They consist entirely of crystals of calcite, resemble lump sugar in colour and structure, and work freely in every direction.

The coloured and streaked marbles contain other metallic compounds and impurities. Examples of a true marble are, the Parian marble used in ancient times in Greece, and Carrara marble from Italy.

It is customary, however, in the trade to describe as marbles every limestone which is capable of taking a bright polish. Many of the English limestones are therefore described as marbles.

Examples of these are the limestones of the Devonian system, marbles of the Carboniferous series from Flintshire, Derbyshire, and Yorkshire, the oolitic limestone of Farne, Stamford, and Yeovil, and the Purbeck and Wealden marbles.

THE DISTRIBUTION OF BUILDING STONES IN SPACE AND TIME

In the opening pages something was said of the cycles of geological change, namely, the elevation of land areas, followed by denudation and the forming of fresh deposits to be again denuded in their turn.

If an examination is made of a place where sedimentary rocks are exposed, either on the seashore or in the quarry, or at a cliff face or the exposed section in a mountain burn, it is in most cases quite obvious that the layers of rock are lying in sheets one above another, or as they are called in "beds."

In most cases also it will be noted that these beds are not lying horizontally as they must have been originally deposited, but are steeply inclined and are "dipping" in some direction.

In geological mapping, direction of the "strike" or direction at right angles to the dip is found by the compass, and the angle of dip is measured wherever a rock face is exposed. Evidently at some subsequent time after their deposition some movement in the earth's crust has tilted the whole mass of rock more or less up on edge.

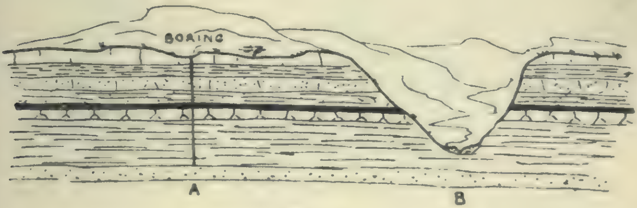

Fig. 1.

The mapping of rocks over a great stretch of country reveals the real nature of this tilting. It is found that owing to lateral pressure the whole mass has in reality been folded or crinkled, thus showing a tilt in any small section.

It is evident from a little consideration that, if it was not for this, we should know little of anything beyond the more recent and superficial deposits, except in so far as borings or deep canyons revealed the nature of the underlying beds.

Fig. 1 represents a section through a series of layers of rock as originally deposited. We can learn nothing of the underlying strata except by means of the bore hole A, or the outcrops of the strata in canyon B.

But if the whole mass of rock has been tilted and then denuded the underlying sections are exposed as shown in Fig. 2.

It is owing to the tilting of the various beds and subsequent denudation that we are able by careful observation, and identification of particular deposits through their fossiliferous remains, to arrange rocks in their order of deposition from the oldest to the most recent deposits. The series of rocks thus revealed have been divided into great groups and named.

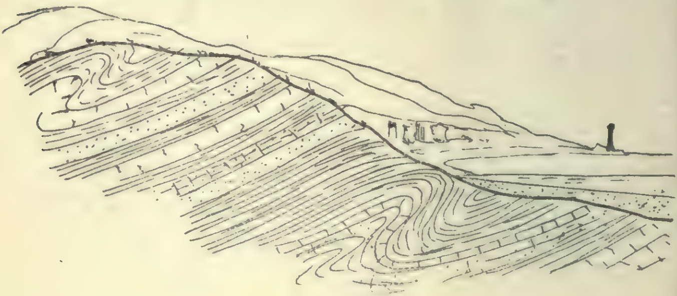

Fig. 2.

A knowledge of this classification of rocks in order of time is of considerable use to the builder, as certain types of building stone are associated with certain geological periods, and consequently a knowledge of the particular group to which a series of "outcrops" belong will guide us in searching for a particular kind of building stone.

By consulting a geological map of a country it can be seen in what regions certain outcrops are found, and therefore in what regions a certain type of building stone is likely to be.

If we suppose the following sketch AB to represent a section cut right across a country showing the series of rocks of different periods one below another, then the same region would be represented in the geological map of the country as shown above.

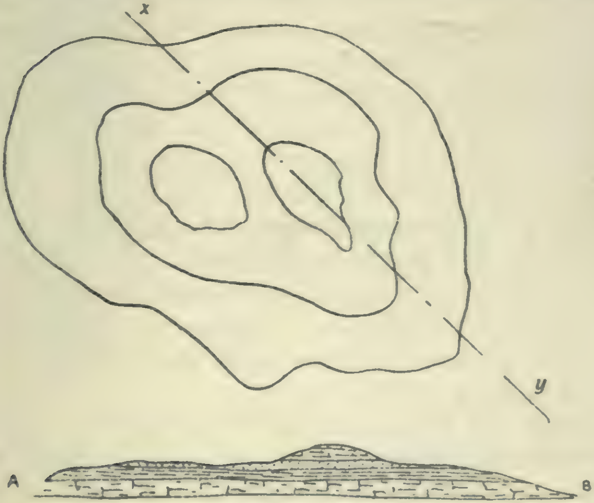

Fig. 3.

Cambrian System.—The oldest rocks, the Cambrian and Pre-Cambrian, crop out principally in Wales and the north of Scotland, and do not contain any building stones of importance. In the north of Scotland the Torridian sandstone belongs to this series. Many of the valuable deposits of slate are found in this group.

Ordovician System.—The Ordovician group of rocks which follows on the Cambrian contain few building stones of importance. The Barren flagstone grits in the south of Scotland are in this formation. Outcrops of the Ordovician series are found in Wales, Shropshire, and Cumberland, which contain flagstones and grits.

Silurian System.—In the Silurian series flagstones are found both in Wales and Cumberland, such as the Wenlock series of flagstones, and coarse red sandstones in the south of Scotland.

Old Red Sandstone System.—Next in order come the "Old Red Sandstone" deposits. The Old Red Sandstone deposits crop out in Cornwall, Devon, Wales, and in the neighbouring counties to Wales. No building stones of importance of the Old Red Sandstone series are found in Cornwall. The Devonian limestone of Devon is an important building stone, and excellent building stones are found in Hereford, Monmouth, Shropshire, Worcestershire, and in Scotland. A broad tract runs from Loch Lomond through Stirling, Perth, and Fife to Stonehaven, with large quarries in Forfarshire. It also runs from Aberdeenshire into Sutherlandshire and Caithness, and is found in the Cheviot district.

Carboniferous System.—Following the Old Red Sandstone deposits, the next in order are the Carboniferous series of rocks which contain the coal measures. The Carboniferous series of rocks supply a very large number of excellent building stones, both sandstone and limestone. Carboniferous rocks are found in South Wales, and stretch in a broad band up the middle of England, from a line north of the Wash to Scotland.

The sandstone and millstone grits of Yorkshire belong to this series, the well-known millstone grits forming a series of strata from which excellent building stones are obtained. Both in this series and in the coal measures lying above them, innumerable sandstone quarries are found both in Lancashire and Yorkshire, and many in Derbyshire, Durham, Cumberland, and in the stretch of country from the Forth to the Clyde in Scotland.

The limestones of the Carboniferous series are not only used as building stone but are quarried principally for the production of lime and as a flux. A well-known limestone used as a building stone in this series is the Hopton Wood stone, Middleton, Derbyshire, very similar in weathering to Portland stone. It has been used in building the Imperial Institute and Manchester Town Hall.

Permian and Triassic System.—The next series of rocks above the Carboniferous series are those belonging to the Permian and Trias series (new red sandstone). These deposits crop out on the south coast of Devonshire extending northwards, spreading out broadly in the Midlands, and then splitting into two branches on each side of the Pennine range. They are also well represented by excellent building stones in Scotland.

This formation contains many excellent sandstone quarries, and also the magnesian limestones. The magnesian limestones run northward in a narrow outcrop from Nottingham through Mansfield, Doncaster, Tadcaster, and Darlington, ending in a broad band at the north coast extending from Hartlepool to South Shields.

Well-known building stones from this formation are the Mansfield and Anston stones. These stones were largely used in building the Houses of Parliament, where their weathering can be studied under the conditions of a large city.

The Jurassic System.—Lying above the Permian and Trias systems come the Jurassic series of rocks. The Jurassic system, which includes the Lias formation, starting at Portsmouth, extends across England to the shores of the Wash, shaped like a Turkish scimitar, and including within its scope, Bath, Oxford, and Bedford. Sandstones are scarce in this formation, but it contains the most important building limestones, namely, Bath stone and the Portland stone beds, and the Purbeck limestone. Below the Great Oolitic series lie the Lias beds, which contain the Lias hydraulic limestones. In these beds are many quarries, such as the Sutton stone from Glamorganshire which has been used in Llandaff Cathedral. The Ketton stone of Rutlandshire is from the inferior oolite. This is the first example we have come across of an oolitic stone. In the Great Oolitic series are found the Bath building stones, many quarries existing in the district surrounding Bath. Above the Great Oolitic series lies the Portland stone best developed in the Isle of Portland. The various beds at Portland are arranged as follows:—

Purbeck beds.
Roach. (Oolitic limestone.)
Whitbed. (Fine-grained oolitic limestone.)
Curf.
Base bed. (Fine-grained oolitic limestone.)

The Whitbed stone has been selected by the Office of Works for building in the London area. Portland stone is obtained from the Isle of Purbeck in Dorsetshire, and from the neighbourhood of Salisbury in Wiltshire. Salisbury Cathedral is built of the Wiltshire stone. The Purbeck stone overlies the Portland stone, and is quarried at Swanage for paving slabs, window sills, etc.

Cretaceous System.— The Cretaceous system covers a great part of the south-east of England within a line drawn from the Wash to Portland. It also crops out on both sides of the mouth of the Humber. The great chalk deposits are found in this system. The chalk is little quarried for building stone. The Beerstone from Beer Seaton, Devonshire, the Kentish Rag from Maidstone, Kent, and the Totternhoe stone from Dunstable, Bedfordshire, are all quarried from the chalk.

Little in the way of building stones are obtained from the tertiary deposits in this country as they are too soft for this purpose.

For full details of the various building stones in the different geological systems, the reader is referred to Howe's *Geology of Building Stones*, more especially for the building stones in England. The following, however, is a list of well-known Scotch building stones :—

NAME OF QUARRY.	COLOUR.	DISTRICT.	BUILDINGS WHERE THE DIFFERENT STONES ARE USED.
Hailes . .	Grey or pink	Midlothian	Used largely in Edinburgh and district.
Corsehill .	Red	Dumfriesshire	National Portrait Gallery, Edinburgh.
Corncockle .	,,	,,	Caledonian Station (partly).
Locharbriggs .	,,	,,	,, ,, .
Closeburn .	,,	,,	Candlish Church Tower, Edinburgh.
Braehead .	Cream	Polmont	Tenements generally in Edinburgh.
Auchenheath .	,,	Lanarkshire	Store Buildings, Cattle Market, Edinburgh.
Ravelston .	,,	Midlothian	Used largely in Edinburgh for rubble work.
Barnton . .	White and blue	,,	Used almost exclusively for monumental work.
Prudham .	Cream	Northumberland	M'Ewan Hall, Edinburgh.
Blaxter . .	,,	,,	Charlotte Street Chapel, Edinburgh.
Millknock .	,,	,,	Tynecastle Police Station, Edinburgh.
Gunnerton .	,,	,,	Chiefly for the late Sir James Steel's property.
Darney . .	,,	,,	Usher Hall.
Woodburn .	,,	,,	*Scotsman* Buildings, Cockburn Street elevation.
Blackpasture .	,,	,,	Redford Barracks (hewn work).
Doddington .	Pink	,,	,, (rubble work)
Pasturehill .	White	,,	Masonic Grand Lodge, George Street, Edinburgh.

CHAPTER II

THE WEATHERING OF BUILDING STONES

THE weathering of building stones is due to a variety of causes all of which require a careful consideration. Wind, carrying particles of gritty dust and sand gradually wears down and pulverises stone. Remarkable examples of the wearing away of exposed rocks from this cause are to be seen in desert regions in which there is no rainfall but limitless supplies of drifting sand.

Rapid changes of temperature by which the stone is expanded and then contracted cause the stone to crack and disintegrate. In dry hot countries there is usually a high temperature during the day, followed by a sudden fall of temperature at night; in such countries the rocks can be heard at night cracking under the sudden cooling with a sound like pistol shots.

Moreover, in a crystalline rock like granite, the different crystals have different coefficients of expansion and contraction, thus causing minute fissures to open by which water can enter and help to disintegrate the rock.

Frost. — The most powerful agency, however, in the disintegration of stone is undoubtedly frost. Water on cooling contracts to a temperature of 4° C., and then on further cooling and passing into ice, expands. This expansion of water is able to exert very considerable pressures, thus breaking up the stone saturated with water. When thawing takes place the broken-up pieces fall away. It might be supposed from this that the most porous stone would be the most subject to destruction by frost. This is not found to be the case in practice, and it is evident that other considerations come in.

If a stone is allowed to soak in water a certain amount of water is absorbed.[1] If the stone is now put under a vacuum, or if pressure is applied a considerably larger amount of water is absorbed, and the ratio between the two quantities of water differs for different kinds of stone. These ratios have been measured for many kinds of stone, and if W is the weight of water absorbed under ordinary conditions, and W' is the weight of water absorbed under pressure, the ratio $S=\frac{W}{W'}$ is called the saturation coefficient of the stone. Now the expansion of water on freezing amounts to nearly 10 per cent., the specific gravity of ice being ·916. If, then, the ratio $\frac{W}{W'}$ is not more than ·8, it is evident that, with ordinary absorption, there is sufficient space left for expansion under freezing without injury to the stone. This ratio is probably, therefore, of considerable importance and should receive attention from architects. The shape of the pores also seems to have an influence on the result, and therefore should likewise be taken into consideration. There is also another factor which has a bearing on the question.

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[1] The author places the stone half-immersed in water under a bell jar. After forty-eight hours the stone is turned upside down, and given another forty-eight hours.

Capillary Phenomena.—A stone can be regarded as consisting of a bundle of capillary tubes with one end open to the air. Now if we take a capillary tube and fill it with a salt solution and leave one end exposed to the air while the other end is in a saturated atmosphere, evaporation and concentration of the solution will take place at the end open to the air.

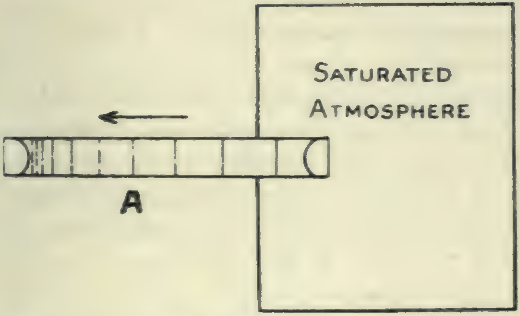

FIG. 4.—A = Capillary Tube, containing salt solution, open to the air at one end.

The concentration of a salt solution in water in most cases alters the surface tensions, so as to draw the liquid along the tube to the outside, and leaving the tube empty. Rain water already contains salts in solution and will, on soaking into the stone, dissolve fresh material in the stone itself. On cooling water containing salts in solution, the first action is the separation of pure ice, leaving a more concentrated salt solution behind, and this will take place on the outer surface of the stone, altering the surface tensions in the ends of the capillaries opening on the outside of the stone, and tending to draw the remaining water out of the stone to the surface. Probably the chance of this happening depends on the rapidity with which the cooling takes place. Once a complete ice plug is formed, the drawing out of the water in the interior can no longer take place.

Innumerable experiments have been made to test the durability of stones by alternately freezing and thawing them. Probably the best method is to soak the stone in water under normal conditions, and not to saturate with water under pressure. The pressure required to crush the stone before treatment should then be compared with the pressure required to crush it after repeated thawing and freezing. As far as possible the rate of cooling should be the same in the case of different stones. It is doubtful, however, if the most careful experiments in this direction give much information of value as to how a stone will behave in practice.

Stones in the lower parts of a wall near the ground may be disintegrated by the soaking in from the ground of water highly impregnated with salts in solution, which crystallise out inside the stone and disintegrate it.

The Solvent Action of Rain and Acids.—Water alone is a solvent for most if not for all minerals, but the solubility of many is so slight that pure water would take a very long time to produce an injurious effect on a stone. Rain water always contains carbonic acid gas which, as has already been explained, has a powerful solvent action on calcium carbonate, and therefore dissolves limestone and disintegrates sandstone in which calcite is the cementing material. A good limestone weathers clean, it dissolves like sugar or salt, it does not disintegrate into a loose powder.

Sandstones disintegrate and a large amount of disintegration may be caused by very little solvent action, if the percentage of binding material is small.

An examination of pieces of Portland stone from Somerset House revealed the fact that there was a hard scab on the outside consisting principally of calcite with some sulphate of lime. A microscopic examination gave indications that the oolitic grains had been attacked to a depth of 4 inches into the stone. Turning back to what has already been said about the capillary action in a stone, it is easy to follow what must have happened. In the first place the rain carrying carbonic acid had soaked deep into the stone dissolving the limestone. Then, when the rain ceased, the evaporation on the outside, causing concentration of the solution, would result in the changed surface tension drawing the solution out of the stone and the depositing of the salts in solution on the surface of the stone. On exposure to the air the calcium bicarbonate in solution would lose its extra carbonic acid gas, depositing calcium carbonate on the surface of the stone.

The weathering of such a stone would take a long time, as there would be the whole mass of the stone to be drawn upon to form a protective outer skin. It is a fact, that contrary to the opinions of chemists, the Whitbed stone of the Portland quarries stands the London climate remarkably well. The question naturally occurs, why do not all limestones behave equally well under the same conditions? Why, for instance, does the stone from the Basebed at Portland weather badly in London?

It, however, is easy to understand why limestones as a whole form good building stones, in spite of their solubility in rain water charged with carbonic acid, while many sandstones weather badly. To destroy a limestone building, a large percentage of stone must be dissolved; to destroy a sandstone only the minute percentage of binding material which hold the quartz grains together need be dissolved.

A very sharp distinction should therefore be drawn in selecting sandstones between those in which calcite is the binding material and those in which the insoluble silica or secondary quartz is the binding material.

Many badly weathering limestones do not dissolve clean like the Whitbed at Portland, but crumble and disintegrate. It is evident that by the solution of material in the body of the stone and the capillary suck toward the surface we have further possibilities of disintegration. If for any reason the crystallisation of the soluble salts take place in a layer just inside the stone, flaking is bound to occur from the pressure of the forming crystals. If, for instance, a stone is treated with a superficial layer of a greasy preservative like paraffin wax or insoluble soap, the crystallisation of salts in solution takes place behind the thin layer of stone with greasy capillaries, and hence such stone preservatives produce flaking. There may be conditions in nature which produce similar results for certain stones. The behaviour of the stone used for many of the Oxford Colleges, and of the limestone used in York Minster, certainly suggest some such action to account for the way they flake off. The greasy layer produced by soot, while probably in some ways a preservative, may act in a similar manner.

Another agent of deterioration remains to be considered.

Sulphur Compounds.—The sulphur in coal burns to form sulphurous acid gas which ultimately oxidises to sulphuric acid.[1] This is a powerful solvent and converts carbonate of lime into the soluble sulphate of lime, and crystallisation of the sulphate of lime and possibly of sulphate of ammonia assists disintegration.

Lichens.—Stones are also destroyed by organic growths such as minute lichens, and the suggestion has more than once been made that the rapid and sudden decay of stones in many instances may be due to the attack of some microscopic fungus.

It is evident that much research is required in this interesting and difficult question.

[1] It has recently been suggested by Jones of Manchester that the attack is principally due not to sulphurous or sulphuric acid but to sulphate of ammonia.

It is probable that progress will be made by the more systematic microscopical examination of stone sections, and more especially by the microscopic examination of sandstone and identification of the cementing material present. It is evident, for instance, that in selecting a sandstone which is to be exposed to the acid laden air of a modern city, a stone should be used in which secondary quartz is the cementing material.

In spite of all the research that has been done on this question, the architect will be well advised to select a stone which experience has proved to stand well in the particular locality, and in cases of doubt to trust more to a microscopic examination of the binding cement, than to physical tests.

He should also be careful to lay the stone in its true bed, and in designing his structure to protect the stone from the soaking in of rain from above.

Preservatives.—Many ingenious suggestions have been made for the preservation of stone by treating with various substances.

The various substances suggested can be divided into two groups:—

(1) Treatment with materials like paraffin wax or insoluble soaps.

(2) Treatment with salt solutions with the view of forming precipitates within the stone.

Paraffin wax dissolved in a volatile solvent is a dangerous preservative, as it is deposited on drying in the upper layer and ultimately results in scaling.

Insoluble soaps, though valuable as additions to Portland cement and sand lime bricks for waterproofing purposes, have not been successful as stone preservatives. The best preservative of this class is linseed oil, thinned with a little naphtha or petroleum, as it remains distributed throughout the stone. It unfortunately discolours the stone.

Of chemical precipitates the earliest tried was a precipitate of silicate formed by treating the stone with calcium chloride and sodium silicate, so as to form calcium silicate within the pores, and the latest preservative of this kind is magnesium fluosilicate. This solution forms an insoluble compound with the calcium carbonate within the stone, in the case of limestones and calcareous sandstone. When calcium carbonate is not present in the stone, the stone is treated with a solution of calcium chloride. As far as the author's experiments go, however, the resulting insoluble compounds do not act as true cements binding the particles of the stone together.

All these solutions are improved in their action by the addition of some 3 per cent. by volume of glycerine. This prevents the change in surface tension, which results in the deposition of the salts near the surface.

Important pieces of stone, such as marble monuments should be immersed in a hot bath of melted paraffin wax before erection.

Any proposed stone preservative should be subjected to the following tests before being used on an important building.

The first test is designed to find out whether the preservative will ultimately do more harm than good. A block of the stone it is proposed to preserve should be treated on one face with the preservative under the conditions laid down by the maker, and then drilled from the surface downwards, and samples taken at different depths and the percentage of preservative present determined by analysis, to find out whether it is fairly evenly distributed inside the stone or concentrated near the surface.

As a convenient reference figure to enable one stone and one preservative to be compared with another, the total amount of water the stone can absorb may be taken as a figure of reference, calling this 100, and plotting the amount of preservative present in percentages of the total amount of water the stone can absorb.

The two following graphs show the application of the same preservative to a limestone and sandstone respectively from the author's experiments, illustrating this method of enquiry very clearly. In the case of the sandstone the preservative is properly distributed within the stone; in the case of the limestone the resulting distribution will almost certainly produce scaling.

In the next place the water absorption of the stone after treatment should be compared with its water absorption before treatment, not only for the total amount absorbed but also for the rate of absorption. It may be stated in passing that many stones in old buildings, with an apparently hard surface, will be found to have an extraordinarily high water absorption, thus showing

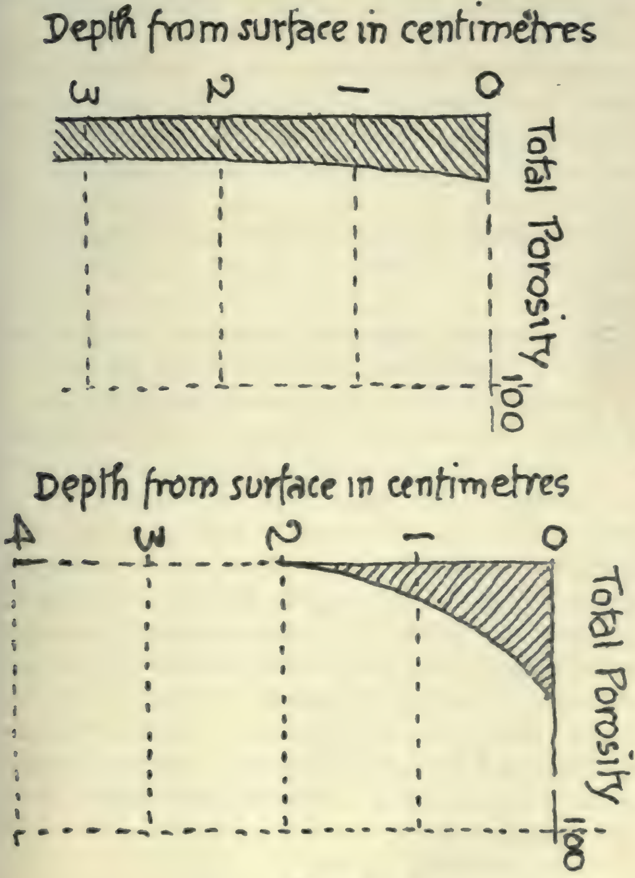

Fig. 5.

that they are already essentially disintegrated and ready to fall to pieces.

The next test should be to take a portion of the stone to the depth to which the preservative has penetrated if it is a calcareous sandstone or limestone, and cut out small cubes of the stone, and expose the sample and a sample of the untreated stone to the action of hydrochloric acid vapour under a bell jar, wash and weigh, and determine the amount of stone dissolved by the acid vapours in both cases.

The author has found that properly prepared solutions of resins are a good preservative for sandstones.

The Physical Testing of Stone.—In the previous section a description has been given of the method of testing stone for water absorption, and also by alternate freezing and thawing, after saturation with water. It is customary in the researches made in Germany and America to allow the stone to take up its full equivalent of water naturally, and to freeze and thaw it twenty times, and then compare the crushing strength of the saturated stone with the crushing strength of the stone after freezing and thawing. This leads us to consider the methods of testing the crushing strength of stone.

For this purpose powerful hydraulic testing machines are used, the stone being cut into a cube, usually about 2 inches each way, and placed between the smooth plates of the testing machine and pressure gradually applied.

The compression of the stone before it actually crushes is noted, and the final pressure necessary to produce crushing. Great care is necessary in making the ends of the test piece perfectly true and smooth, so as to get an even distribution of pressure. Some observers coat the surface in addition with plaster of Paris.

The crushing load of granite is between 900 tons to 1300 tons per square foot, of sandstones from 200 tons to 1000 tons per square foot, and limestones from 60 tons to 550 tons. Portland stone varies from 200 to about 300 tons.

The crushing load which ordinary building stone can carry is far above any loads to which it is subjected in ordinary practice.

At the same time even granite may crack under a badly distributed load. Steel beams carrying heavy loads and resting at the ends on stone blocks may cause the stone to crack if the load is concentrated on one point. The end of the beam should be planed true and laid on a thin sheet of lead.

Stone may also be subjected to tensile tests, though this is seldom done. The method of making tensile tests will be thoroughly described under cements. Shearing tests, in which the pressure is applied close to the grip holding the stone, and tests as beams have also been made. None of these are of much importance in practice as the ordinary conditions of use are far below the strength of stone. (For diagrams see pp. 126, 127.)

Specific Gravity.—The specific gravity of stone may be defined in two ways. The specific gravity of a block of stone with all its pores filled with air, and the specific gravity of the stone material. The weight of a block of stone in air and water enable the specific gravity of the block to be determined from the formula: Sp. gr. $= \frac{W}{W - W'}$ when W is the weight in air and W′ the weight in water. Partial absorption of water into the pores is one source of error, and the conditions of drying the stone is another source of error. The stone should be thoroughly dried for some time at about 50° C.

Another method used by Tetmajer is to coat the stone with a thin layer of paraffin wax before weighing.

The specific gravity may also be determined by displacement and measurement of increase of volume of the liquid.

The specific gravity of the stone material is determined by powdering the stone, introducing a known weight of the powder into a specific gravity flask containing water. The specific gravity flask should be placed under an air pump for some time to draw off all occluded air. Then if W′ is the weight of the powdered stone, W″ the weight of the water the flask holds alone, and W‴ the weight of the powder and water, then—

$$\text{Sp. gr.} = \frac{W'}{W' + W'' - W'''}.$$

By determining the specific gravity of the block of stone, and of the powdered stone respectively, the porosity of the stone can be calculated. If P is the percentage of pores, then—

$$P = \frac{(\text{Sp. gr. of powder} - \text{Sp. gr. of block})\ 100}{\text{Sp. gr. of powder}}.$$

The measurement of water absorption has already been discussed.

The following table from Hirschwald's results gives an idea of the varying porosity of sandstones and the ratio of natural saturation W′ to saturation under a vacuum W″:—

Sandstones.	Percentage of Water absorbed.	
	Natural.	Under Vacuum.
A	1·63	2·21
B	3·58	6·35
C	5·66	9·23
D	4·75	7·44
E	6·80	9·68
F	8·48	12·90
G	11·39	14·75

Abrasion.—Stones to be used for paving or for door-steps should be examined by the abrasion test. The method used by the Charlottenberg Institute is the best. A cube of stone with a face of 50 sq. cm. is pressed with a pressure of 30 kg. against a rotating cast-iron disk. The stone is 22 cm. from the centre of the disk, and the disk makes 22 revolutions per minute. Once a minute the disk is fed with 20 gram. of No. 3 Naxos emery. The loss of weight of the cube is determined after 110 revolutions.

Rattler Test.—For road metal the Rattler test is the best, fragments of the stone being placed in a rotating cylinder with ribs inside.

CHAPTER III

LIME, NATURAL AND PORTLAND CEMENT, BLAST FURNACE SLAG, PLASTER OF PARIS, MAGNESIA

In the former chapter on building stones a certain amount of information has been gathered as to the chemical composition of the materials of which they are composed.

In order to understand the nature and properties of lime and cements, it will be necessary to consider the composition of such substances a little more closely. Before doing so it will be as well to explain for those who are ignorant of chemistry in what way the chemist builds up the name of a substance. In the first place, to take an example, he proceeds to the examination of a piece of limestone or a piece of chalk, and he finds that on strongly heating a substance to which the name of quicklime has been given is left, and this substance on wetting with water gets very hot and crumbles to powder. At the same time the water disappears and a substance known as slaked lime is left.

The first step taken by the chemist when proceeding to investigate such common results of practice is to repeat the operation, carefully weighing the material at each stage. He finds, for instance, that the chalk on being heated and converted into quicklime has lost in weight. He then proceeds to search for the missing constituent that the chalk has lost. We are here, as already explained, following in the footsteps of Black, whose chemical researches laid the foundations of modern chemistry. Black found that what was lost on heating the chalk was a gas to which he gave the name of "fixed air," the same gas produced by treating the chalk with an acid and by the burning of charcoal in the air.

Now the elementary substance of which charcoal is composed is also found in other forms such as graphite and the diamond, and to all the forms the common name of carbon has been given.

There the matter stood for a long time, until it was discovered that quicklime itself can be broken up into oxygen and a metal to which the name calcium was given. Therefore quicklime is called by the chemist calcium oxide. When water is poured on quicklime the whole mass gets hot, falls to powder, and dries up. If it is now weighed it will be found to have increased in weight owing to the combination of the calcium oxide and the water to form calcium hydrate or slaked lime.

A little familiarity with the methods by which the chemist builds up the name of a compound will prove of great use to the student as the chemist's name for the substance reveals its composition. Sometimes more than one name is familiarly used, the name having been modified as the composition of the substance has been better understood. If we are speaking of the different stones all composed of the same substance, calcium carbonate, we know of them as marble, limestone, and chalk. If we are speaking of the same substance in its usual crystalline form we speak of it as calcite. Speaking loosely and using old nomenclature we call it carbonate of lime. Speaking accurately we call it calcium carbonate, which at once tells the chemist that it is the oxide of the metal calcium combined with carbonic acid gas, or, as it is more usually called to-day, carbon dioxide.

The Manufacture of Quicklime.—The heating, or as it is inaccurately called the "burning," of limestone takes place in some form of limekiln. The temperature necessary for its complete decomposition is 900° C., and 100 lb. of stone gives 56 lb. of quicklime. In the old-fashioned kiln the limestone and fuel are mixed together, and the quicklime contains the coal ashes drawn out from below. The introduction of a jet of steam facilitates the process.

In the modern type of kiln the process is continuous, the burning fuel being kept apart from the limestone. This yields a purer lime than the older process.

The lime obtained from a pure limestone should be white in colour and should be in lumps. The presence of much powder shows that it has been exposed to the air too long. A pure lime should show on analysis 95 to 98 per cent. of quicklime, and should slake rapidly and well. Such limes are called fat limes as distinguished from hydraulic limes, which will be presently considered.

Slaked Lime.—With a pure lime the amount of water required to form slaked lime (calcium hydrate) is

32 per cent. of the weight of the quicklime. During slaking the lime increases from two to three times in volume. The complete slaking of lime is not an easy operation. If too much water is added the lime is weakened, if too little the slaking is not complete. Moreover, the lime is sure to contain some portions underburnt and overburnt, and other portions containing silica. Such portions slake very slowly and are apt to cause blow-holes and cracking. For ordinary mortar the rough slaking usually practised is probably good enough.

Lime Plaster.—For lime plaster more care is necessary, and it is usual to specify that the lime must have been slaked and made into a cream with water several weeks before use. This material is known as plasterer's putty. To make it set more quickly a little plaster of Paris is sometimes mixed in just before use.

A much better plan, which is widely used in America, is for the lime burner to supply calcium hydrate, that is, lime already slaked. This lime has been slaked under proper conditions and carefully sifted, and is ready for use for lime plaster.

Magnesian Lime.—The preparation of lime from a magnesian limestone is only carried out in certain districts in this country. A magnesian lime slakes more slowly with less swelling and disengagement of heat. It forms quite a satisfactory lime for building purposes.

Hydraulic Limes.—Hydraulic limes are limes which can set under water and approach in their properties towards Portland cement.

Such hydraulic limes are common in the "Blue Lias" limestones in this country. They slake much more slowly than ordinary lime, and should be finely ground to ensure thorough hydration.

They ultimately set into a much harder and more durable mortar than fat lime. The Arden lime from the west of Scotland is a hydraulic lime. In the course of years they reach a strength under compression approaching that of Portland cement, but at first are much weaker under both compression and tensile strength.

While a good Portland cement mortar consisting of 1 cement to 3 sand gives under tension a test of 300 lb. to the square inch, the tensile strength for a Blue Lias lime mortar of the same composition is 95 lb. per square inch.

The Blue Lias limes also take their first set much more slowly. If some 5 per cent. of gypsum is added to the Blue Lias lime it gives a better test under both compression and tension, a mortar of 1 : 3 testing under tension about 140 lb. to the square inch. In addition the time of the first set is much diminished, making it practicable to use it for the making of concrete blocks in moulds. Such a cement is known as selenitic cement.

Hydraulic limes are found both in America and in France, approaching much more nearly in their properties to Portland cement than English hydraulic limes. The chemical changes taking place in the hydraulic limes when setting will be considered later. For the pointing of old buildings they are preferable to fat limes, giving a stronger and more durable job, and to Portland cement, which draws away from the stone. And in fact they are preferable to fat limes for all building operations, but not so suitable for making lime plaster.

Other natural and artificial cements will be considered later. At present we will proceed to discuss the most important of all cements, namely, Portland cement.

Portland Cement.—Portland cement is manufactured by heating at a very high temperature (about 1500° C.) a properly proportioned mixture of carbonate of lime and clay. There is much that is still obscure about the changes that take place both in the manufacture and hydration of Portland cement, but certain facts are known which are sufficient to give a fairly definite conception of the changes which take place.

In the opening chapters on stones, silica, the substance of which quartz is the crystalline variety, was mentioned, and alumina the oxide of aluminium, and hydrated silicate of alumina or china clay.

All clays consist principally of hydrated silicate of alumina, with compounds of iron as the principal impurity. Some account was also given of acids and bases, and it was explained that the oxides of the metals or bases combined with acids, and that silica at a high temperature behaved as an acid combining with bases to form silicates. There are certain metallic oxides of which alumina is an example which are capable of playing a double part. They can act as bases, forming compounds such as the silicate of alumina already mentioned, but they are also capable of acting as acids in the presence of strong bases such as lime combining to form calcium aluminates.

Apparently, then, on heating together the clay and limestone, the limestone loses its carbonic acid becoming quicklime, and this combines with both the silica and the alumina in the clay to form a mixture of calcium silicates and aluminates.

During the making the temperature rises sufficiently high to form a clinker, thus providing a condition of partial fusion. As has been already found on considering the formation of granite, in such a fused complex mixture, on cooling, crystallisation of different minerals takes place at various temperatures, the last to cool being the mother liquor from which the various crystalline bodies have separated, which is known as the eutectic mixture.

On mounting a piece of Portland cement clinker in Canada balsam and grinding down till a very thin slice is obtained and examining under the microscope, several crystalline bodies can be identified. Of these the two most important are both of them compounds containing both silicate and aluminate of calcium to which the names alite and celite have been given.

On the addition of water both these bodies are decomposed and combine with the water to form new groups of hydrated calcium silicates and aluminates. If the hydration is watched under the microscope, the little dark particles of the cement are seen to be attacked and to be rapidly surrounded by a swelling gelatinous mass with little unattacked particles in the middle. In addition crystals of calcium hydrate are formed. This gelatinous mass slowly hardens cementing the whole mass together.

If the cement after setting is reground the unattacked particles are exposed and on addition of water the cement is capable of again setting. The above explanation does not cover all the facts, but it is sufficient to give us a general intelligent conception of what takes place. In the case of natural cements and hydraulic limes some similar process no doubt takes place, and in the case of cements formed by mixing lime with a material containing silicate of alumina in a condition to be readily attacked such as the volcanic tuffa of Naples, the formation of these hydrated silicates and aluminates apparently takes place slowly at ordinary temperatures.

The present manufacture of Portland cement takes place in long rotating furnaces, slightly inclined. The clay and limestones are usually finely ground into a slurry which is fed in at the top end of the tubular furnace; the flames from an exterior furnace are led in at the bottom end. The rotation causes the slurry to work slowly down the tube, first drying, then being calcined at a higher and higher temperature till it finally comes out at the lower end as a clinker or frit, which then has to be finely ground and is then ready to be sold as Portland cement. In some cases the raw materials are ground together dry.

The finer the grinding the better the cement.

A little gypsum is usually ground in to retard the setting slightly on the addition of water.

Portland cement is made principally in this country on the Medway, where the chalk and the Medway mud form excellent raw material; but it is now known that a great variety of clays and limestones, if combined in the proper proportion, make excellent Portland cement.

Materials require to be selected which are free from sulphates and magnesia, and the clay should be free from sand. The proportions used are about 75 per cent. of limestone or chalk to 25 per cent. of clay. In considering the proportions of the various constituents in Portland cement, two facts must be kept in mind. (1) An excess of lime uncombined will result in a cement which will swell and crack after setting. Such swelling and cracking may be also caused by imperfect heating during making. (2) The higher the percentage of lime within limits the stronger the cement. (3) A high percentage of alumina makes for quick setting, but is not advisable in a cement which is to be used for concrete walls exposed to sea water. A safe practical formula for cement is, that the percentage of lime should equal the percentage of silica × 2·7 + the percentage of alumina × 1·0.

A typical analysis of a good Portland cement is as follows:—

Insoluble in Hydrochloric acid .	1·14
Silica	22·94
Alumina	7·12
Ferric oxide	3·24

(Lime) Calcium oxide	60·70
Magnesium oxide	1·25
Sulphur	1·36
Water and carbonic acid	1·18
Alkalies	1·07

It is usual to add to the Portland cement some 2 per cent. of gypsum to retard the rate of setting: an excess of gypsum above this amount is injurious.

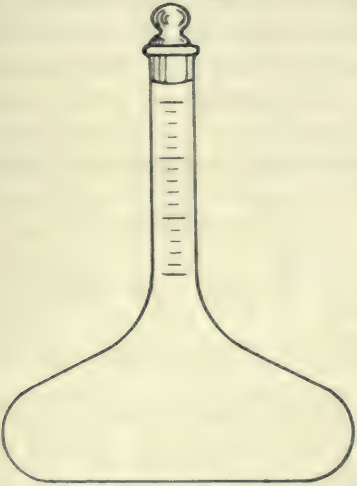

Fig. 6.—Flask for determination of specific gravity.

The Testing of Cement.—Besides the chemical analysis of a cement to be selected for building purposes it has to pass certain other tests.

The most important of these are:—

Specific gravity, fineness of the particles, rate of setting, tensile strength, and absence of expansion after setting.

Specific Gravity.—The specific gravity is determined in a broad bottomed flask with a narrow neck, graduated into cubic centimetres. The lowest graduation should represent a capacity of 64 c.c.

Fifty c.c. of dry paraffin oil is introduced into the flask, and 50 grams of cement weighed out and introduced.

The introduction of the cement causes the paraffin oil to rise in the neck of the flask, to an amount measuring the volume of the Portland cement. To obtain the specific gravity, divide the weight of the cement by the number of cubic centimetres it occupies.

Suppose the cement occupies 16 c.c., then

$$\frac{50}{16} = \text{specific gravity.}$$

The British Standard Specification requires a specific gravity of not less than 3·15 for fresh cement, or 3·10 if it is known to be at least four weeks old.

Fineness of Grinding.—The tensile strength of neat cement is not increased by fineness of grinding, but the tensile strength of cement mixed with sand continues to increase the more finely the cement is ground. This is shown by the following figures:—

(1) Cement of which 35 per cent. was retained in a No. 120 sieve gave a tensile strength of 403 lb. per square inch. A 1 to 3 mixture of this cement with sand gave a tensile strength of 105 lb. per square inch.

(2) Cement of which 12 per cent. was retained in a No. 120 sieve gave a tensile strength of 304 lb. per square inch. A 1 to 3 mixture of this cement with sand gave a tensile strength of 181 lb. per square inch.

In order to completely determine the fineness, a series of sieves are used consisting of a finer and finer mesh of wire gauze.

For the British Specification only two sieves are required. The coarse sieve has 76 holes to the linear inch, the diameter of the wire being ·0044 in. The finer sieve has 180 holes to the inch, the diameter of the wire being ·0018 in. According to the British Specification the residue left in the coarse sieve should not weigh more than 1 per cent. of the whole, and the residue left in the finer sieve not more than 14 per cent. of the whole. Modern well-made cements are usually much more finely ground than this standard requires.

Tensile Strength.—Portland cement as used in a building is required to carry a load, and is therefore exposed to crushing. If in the course of construction it is anywhere to be exposed to a pull that is a tensile stress it is usual to reinforce with steel, a material obviously much more suitable for being subjected to this treatment. In practice, however, though many compression tests of cement have been made, it is usual to be satisfied with a tensile or pulling test as the two are roughly proportional to each other, the proportion varying from 1 to 8 to 1 to 10. The kind of machine used for compression tests has already been described under the tests for building stones. The method of applying tensile tests to cement and mixtures of cement and sand is as follows: The cement or cement and a sand which is obtained from Leighton Buzzard and is known as standard sand, is mixed with the right proportion of water and well kneaded with the fingers and packed into a mould of brass of the shape and size shown in the diagram and allowed to set.

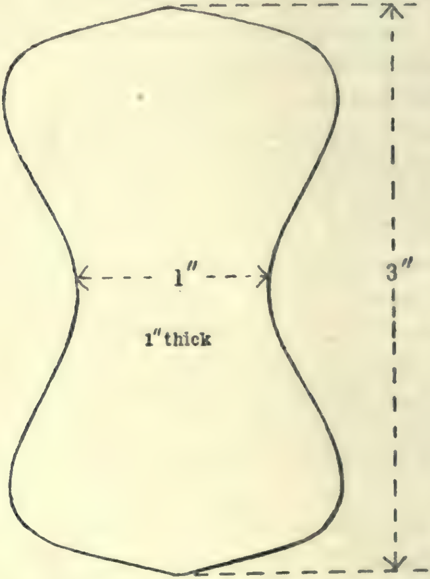

Fig. 7.—**Standard form of Briquette for tensile tests.**

It is then removed from the mould and kept in a moist air-chamber for twenty-four hours.

It is then placed under water and kept under

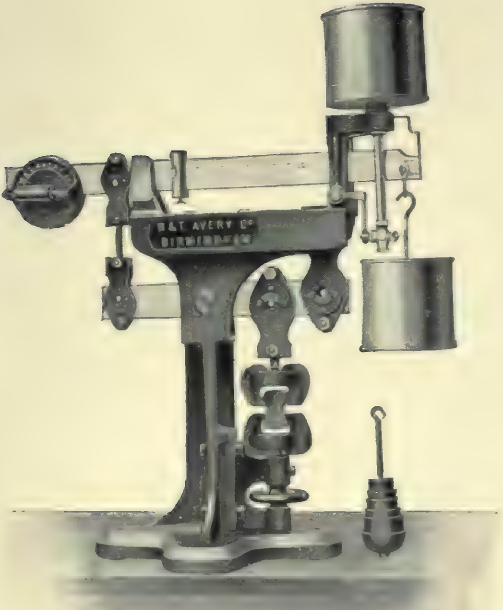

Fig. 8.—Testing Machine.

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water as near the temperature of 21° C. as possible, until removed for testing.

There are many types of testing machines in use. The object to be obtained is to subject the briquette to a gradually increasing tension at the known rate of 600 lb. per minute. A modern type of testing machine is shown in Fig. 8.

The following table from Taylor and Thompson shows the strength of cement and cement mortar under compression and tension in lbs. per square inch:—

Proportion by Weight.		Compression.	Tension.
Cement.	Sand.		
1	0·0	8040	698
1	1·0	5000	510
1	2·0	4380	415
1	3·1	2720	320
1	4·1	1990	278
1	5·0	1510	240

These values are taken from the more elaborate table by Monsieur Feret, recalculated by Taylor and Thompson into English units. The figures are selected from columns dealing with the results for different sands.

The strength of the cement increases with time. According to the British Standard Specification, briquettes of neat cement kept under water for seven days after drying for twenty-four hours must have a tensile strength of not less than 450 lb. per square inch, and after twenty-eight days the tensile strength of seven days + 40,000 lb. divided by the tensile strength of seven days. Mortars of 3 parts standard sand and 1 part cement must have a tensile strength of 200 lb. after seven days, and after twenty-eight days not less than tensile strength at seven days + 10,000 lb. divided by tensile strength at seven days.

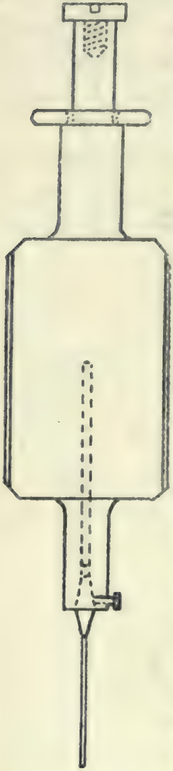


FIG. 9. — Needle prescribed by British 1907 Standard Specification (Desch).

Time of Initial and Final Set.— The Vicat needle consists of a slender cylindrical rod loaded with a definite weight, with a cross section of 1 sq. mm. The cement made up to normal consistency is placed in a cylindrical mould below the needle. The initial set is said to have taken place when the needle is no longer able to penetrate through the whole thickness of the cake of cement. The final set when the needle carefully lowered no longer makes an appreciable impression. To test whether the cement is made up to the right consistency, replace the needle by a cylinder 1 cm. in diameter. The cylinder should penetrate the cement to within 6 mm. of the bottom of the mould.

Testing for Expansion after Setting. — For this purpose Le Chatelier's apparatus is used. This consists of a split ring with two long pointers attached.

The cement is gauged and filled into the ring placed on a glass plate, and another glass plate held down by a weight placed on the top.

The whole is immersed in water at 15° C. for twenty-four hours. The distance between the tips of the pointers is then measured, and the whole apparatus is placed in water which is raised to boiling-point in half an hour and is kept boiling for six hours; the distance between the pointers is again measured. The increase in distance must not exceed 10 mm. when the cement has been aerated for twenty-four hours, or 5 mm. when it has been aerated for seven days.

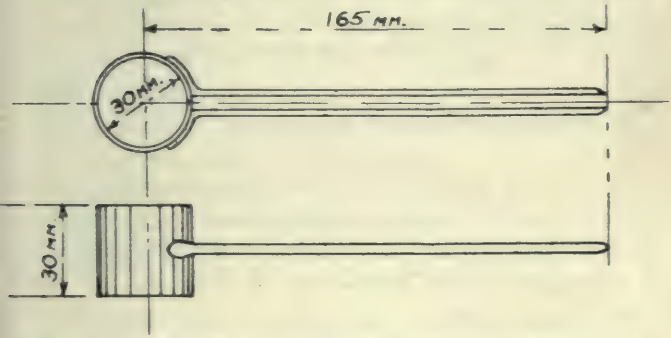


Fig. 10.—Le Chatelier's Apparatus for measurement of expansion.

Shearing Tests.—So far we have considered the testing of cement under compression and under tension. In order to test the resistance of a cement to a shearing stress, the cement block is held between two pieces and the force applied close to the support.

Transverse Tests.—When cement slabs have to carry a load between two supports, transverse tests of the strength of the cements are very useful. If a beam be supported at the two ends, and loaded at the centre, and if W = the breaking load in lbs., l = length of beam between supports in inches, b = breadth of beam in inches, h = depth of beam in inches, and f is the resistance offered by the extreme fibre "or the modulus of rupture," then

$$f = \frac{3Wl}{2bh^2} \text{ in lbs. per square inch.}$$

For distributed load $f = \frac{3Wl}{4bh^2}$.

In testing cements, the beams are made 2 cm. in the side and 12 cm. long and placed on knife-edges 10 cm. apart. The load is applied at the centre with a slightly rounded knife-edge at the rate of 1000 grams per second.

Permeability or Percolation Tests.—For this purpose a cylindrical block is prepared with a pipe cemented to the upper surface. The permeability is measured in the number of litres of water passed in one hour through a block of known thickness.

Modulus of Elasticity.—If a steel rod is suspended from one end and a weight hung on the other end, the rod will be stretched.

If the weight is now taken off and has not been so heavy as to stretch the rod beyond its "elastic limit," the rod will contract to its former length. If the length of the rod is measured before the weight is attached and then measured again after the weight has been attached, then the increase of length divided by the total length of the rod is the amount of stretch or the strain for that rod.

If, for instance, 1 in. is taken for our standard of length and the rod is 10 in. long and has stretched 0·1 of an inch, then the amount of stretching per unit length of 1 in. is 0·01 of an inch. It is obvious also that the amount of stretching will increase with an increase of the weight, and will diminish the thicker the rod. The "modulus of elasticity" is defined as the stress per unit area divided by the deformation or strain per unit length.

Therefore if P be the total load in lbs.,

A the area of section of the rod,

L the length of the rod,

e the actual elongation in inches,

then the modulus of elasticity $= \mathrm{E} = \dfrac{\mathrm{P\,L}}{\mathrm{A}\,e}$.

In English measure the unit area is 1 sq. in., the unit load 1 lb., and the unit length is 1 in.; the strain is also measured in inches and fractions of an inch, and the value of E is thus given in lbs. per square inch.

If instead of extending the substance it is compressed, the modulus of elasticity can be determined in compression. The results of experiments are to show that the value of E for extension and compression are for all practical purposes the same.

The determination of E under compression for cement and cement mortars offer many practical difficulties and only approximate figures have been obtained by compression tests. The discussion of the modulus of elasticity for cement and concrete will be resumed when discussing concrete. The determination of the modulus of elasticity of cement and concrete is of practical importance in making the necessary calculations for reinforced concrete design.

Addition of Hydrated Lime to Cement.—The addition of a certain amount of hydrated lime to cement increases the tensile strength, but if the amount becomes excessive the tensile strength diminishes. The following table of results obtained by Mr Wheeler is very instructive:—

Cement in lb.	Lime in lb.	Sand in lb.	Tensile Strength, 28 days.
200	0	600	201
200	20	600	242
180	20	600	238
150	50	600	168
100	100	600	57

Gypsum.—Large deposits of gypsum exist in various parts of the world. In this country the principal sources of supply are found in the Keuper series of rocks. Gypsum mines are worked in Sussex, Derbyshire, Nottinghamshire, and Cumberland, the principal deposits being those found in the Nottingham district. Gypsum is a sulphate of calcium combined with a certain percentage of water, its formula being $CaSO_4 . 2H_2O$. On heating the material it begins to lose the water of combination, the amount of loss of combined water depending on the temperature to which it is heated. The preparation of common plaster of Paris is carried out as follows: The gypsum having been ground is heated with constant stirring to a temperature of about 200° C.

As the temperature rises, the gypsum begins to boil, that is, the powdered mass bubbles like boiling water owing to the disengagement of the combined water as steam. When the right percentage of water has been driven off, the material remaining is known as plaster of Paris. If this material is again mixed with water the calcium sulphate recombines with water to form the original gypsum, and during the recombination sets into a hard compact mass. After having set, the plaster of Paris takes from about three to four weeks to arrive at its final strength.

Plaster of Paris can be used either as a finishing plaster, or moulded into slabs, for use in the formation of partitions and other forms of internal construction. Owing to the fact that calcium sulphate is slightly soluble in water it is not regarded as suitable for external work, though as an actual fact it was used as a mortar in many medieval buildings, in which the mortar has stood the test of time, and has also been used in certain districts on the Continent for external construction.

The use of plaster of Paris for internal construction is much commoner on the Continent and in America than in this country. The brittleness of the material has led to a want of recognition of its strength under steady loads, both under compression and under tension. Tests made by the Munition

Inventions Department show that ordinary pink plaster of Paris made in this country breaks down under an ultimate load of ·94 ton per square inch. This figure agrees closely with similar tests made of plaster of Paris in America. Experiments made by the National Physical Laboratory gave the following results of the application to plaster of Paris slabs, 18 in. × 9 in. × 3 in. of pressure on the edge of the slab.

Crushing Load in Tons per Square Foot.

A	A	B	B	C	C	D	D
5·6	4·9	4·8	3·7	5·5	8·4	16·6	27·8

These figures are the pressures at which cracks appeared. A and B were gypsum slabs containing reeds. C contained coke breeze and reeds. D contained wood wool. The amount of reeds in C was doubtless much less than in A and B. It is evident from the results obtained with C and D, that these slabs were able to stand very heavy crushing loads without cracking.

Reeds are introduced in the manufacture of slabs to enable them to be more easily handled, but evidently result in a very serious diminution of crushing strength. In an experiment carried out by the Munitions Inventions Department and the Office of Works, a partition wall, containing a door, was constructed 8 ft. high by 12 ft. long, with partition slabs, 6 ft. by 12 in. by 3 in. thick, and loaded to destruction.

The load under which it ultimately collapsed was 1 ton 16 cwt. per foot super on the top of the partition wall. This wall was built with slabs containing reeds corresponding to samples A and B. It is evident if these results be compared one with another, that 3-in. partition slabs without reeds can carry with safety considerable loads. In France partition slabs from 2 in. to 4 in. thick are made of plaster of Paris and coke breeze, and in Canada 3½-in. slabs are used and carry the ordinary loads obtaining in cottage construction.

Hard Baked Plaster.—If the gypsum is heated to about 700°-900° a plaster is obtained which sets very slowly but forms a very hard durable surface. Such plasters were formerly used in England as flooring plasters, and are extensively used on the Continent for this purpose. In this connection the following table of results obtained by the M.I.D. on the breaking load of plaster beams is of interest :—

Material.	Age.	Specimen.	Distance between Knife-Edges.	Width of Beam.	Depth of Beam.	Load required to break Beam.
White plaster .	3 weeks	1	11 in.	1 in.	1 in.	29·8 lb.
		2	11 ,,	1 ,,	1 ,,	29·4 ,,
		3	11 ,,	1 ,,	1 ,,	30·3 ,,
Pink plaster .	3 weeks	1	11 ,,	1 ,,	1 ,,	26·4 ,,
		2	11 ,,	1 ,,	1 ,,	27·2 ,,
		3	11 ,,	1 ,,	1 ,,	28·1 ,,

If l is the length of the beam in inches, W is the weight applied in the centre of the beam, b

the breadth in inches, h the depth in inches, the modulus of rupture can be calculated from the formula $f=\frac{3Wl}{2bh^2}$.

On the examination of old floors in the neighbourhood of Nottingham, still in good condition, it was found that reeds had been laid between the beams to carry the plaster, that the distance between centres was 16½ in. and the plaster some 2½ in. thick. It was the custom to harden the floors by treating when finished with linseed oil. This prevents dusting off of the plaster. Wire netting and expanded metal are sometimes used to support plaster or to reinforce plaster slabs. Some doubt has been expressed as to the possible corrosion of steel under these conditions, and elaborate experiments on the whole favourable to plaster have been made in Columbia University. As a result of their own experiments the M.I.D. came to the conclusion that the addition of a small percentage of lime to the plaster removed all danger of corrosion.

Patent Plasters, Parian Plaster, and Keene's Cement.—It has been found that on heating plaster of Paris with small percentages of sulphate of alumina, borax, and potash salts, plasters are obtained which set with a much harder surface and therefore are useful as finishing plasters. Several plasters are in the market under different fancy names based upon these facts. Though doubtless useful for their special purpose their crushing strength as tested by the M.I.D. is not equal to common plaster of Paris, and therefore they are not to be recommended for constructional work where a load has to be carried.

The following table gives the results of heating gypsum to different temperatures :—

Temperature of Formation.	Nature of Product.	Remarks.
107° C.	Hemihydrate.	……
107° to 170° C.	Mainly hemihydrate.	Plaster of Paris.
170° to 200° C.	More or less dehydrated hemihydrate. Set rapidly to form hemihydrate.	Set with water owing to formation of crystals, *i.e.*, set with alteration of form.
200° to 250° C.	Contains small quantity of water. Sets slowly at first with formation of hemihydrate.	……
250° to 400° C.	Contains traces of water. Sets very slowly.	……
400° to 750° C.	Anhydrous calcium sulphate, practically dead-burned.	……
750° to 800° C.	Beginning of formation of flooring plaster.	Set slightly or not at all.
800° C.	Flooring plaster with cryptoform of the granular anhydride.	When treated with alum set owing to formation of crystals, *i.e.* with change of form.
900° to 1000° C.	Normal flooring plaster with full development of granules.	Set slowly with water without alteration of form.
1000° to 1400° C.	Flooring plaster with granules of increased size and hardness and rising content of basic sulphate.	……

Pozzuoli Cement.—Certain substances containing silicates of alumina in a special condition are able when mixed with lime to form hydraulic cements.

The oldest and best known material of this kind is Pozzuolana, which derives its name from a little town near Naples. This material is a volcanic tuff, consisting essentially of silicates of alumina and iron with a small percentage of lime. Another similar volcanic tuff known as Trass is found in the neighbourhood of the Rhine. In addition, there are the Santorin deposits obtained from one of the islands in the Greek Archipelago and the deposits found in South-eastern France.

Other similar deposits occur in various parts of the world. All these substances when mixed with lime form a cement which ultimately becomes very hard. The Pozzuoli cement mixed with lime was used by the Romans in Italy for making mortar and concrete.

Powdered bricks and lightly burnt clay have similar properties. Though the crushing strength of such mixtures is low as compared with Portland cement concrete, they have been proved by the test of time to be very durable and to slowly increase in strength, and therefore their possible use as a building material for the making of concrete suitable for cottage construction, is worthy of the serious consideration of architects.

Blast Furnace Slag.—Blast furnace slag has similar properties to Pozzuoli cement, and when properly selected makes an excellent cement approaching closely to Portland cement in crushing strength.

The fused slag is run into water and granulated.

By this process it is converted into a convenient condition for grinding, and at the same time its hydraulic properties are improved and part of the sulphur it contains removed.

It then can be prepared for cement by three processes. (1) It is merely dried and ground. (2) It is dried and ground and intimately mixed with a certain proportion of slaked lime. (3) It is mixed with lime and calcined in kilns, thus producing a product corresponding to ordinary Portland cement. Cement made by one of these three processes have long been manufactured on the Continent and in America, and at one time the Skinningrove Iron Company manufactured a cement from slag in this country by the first process given above. At present a slag cement is manufactured by the Coltness Iron Company and the Glasgow Iron and Steel Company, and before the war a cement was being manufactured in Germany known as iron cement, being a mixture of two-thirds of cement made by the third process, with a third of cement made by the first process.

These cements, as already stated, approach closely to Portland cement when mixed with sand in their resistance to crushing. The objection to them is that they are apt to contain too high a percentage of sulphur in a form which oxidises in the air to sulphates and so results in the cracking of the cements. Judging by the recent analyses of such cements this difficulty has been overcome, and there should be a great future for blast furnace slag cements as they are both cheap to manufacture and strong, while very large supplies of the raw material is available as a waste product of iron manufacture.

Magnesite Cements.—Reference has already been made to magnesium carbonate which is found associated with calcium carbonate in the rock known as dolomite. Deposits of pure magnesium carbonate or magnesite are found in Greece and in other parts of the world. This material when calcined loses its carbonic acid gas, leaving the anhydrous magnesium oxide which is used in the manufacture of basic furnace bricks. The white ground magnesite can be obtained from the manufacturers of basic furnace bricks. If magnesite is mixed with a solution of the salt of magnesium known as magnesium chloride, the resulting mixture sets into a very hard white cement owing to the combination of the two ingredients to form magnesium oxychloride. For this purpose the solution of the magnesium chloride should be made up of a strength to register 34° Tw. specific gravity, and this liquor be mixed into a stiff paste with the magnesite. This solution contains about 400 parts of magnesium chloride in 500 parts of water. This cement has been largely used mixed with sawdust as a flooring material and is sold under various fancy names. One of the mixtures sold was found to contain 10 per cent. by weight of sawdust and 15 per cent. by weight of red oxide.

CHAPTER IV

CONCRETE

CONCRETE is a mixture of cement, sand, and a coarse aggregate which may consist of gravel, crushed rock, burnt ballast, well weathered blast furnace slag, slag from various metallurgical operations, clinker or breeze, or any other suitable material which has a sufficient crushing strength for the purpose.

Blast furnace slag and breeze must both be used with caution owing to the danger of the contained sulphides oxidising, but many other furnace slags and clean clinker are excellent materials for an aggregate. Chalk is being tried as an aggregate for cottage building. Its weathering properties would probably be improved by spraying the outside with silicate of soda containing some 3 per cent. of glycerine in the solution.

The problem before the builder is to obtain the concrete of the greatest cementing strength with the minimum of cement. The solution of this problem involves a careful study of the close packing of mixed material of various sizes. The two laws governing the making of concrete are as follows:—

> "With the same aggregate the strongest and most impermeable concrete is that containing

> the largest percentage of cement in a given volume."
>
> "With the same percentage of cement in a given volume of concrete made with the same sand and aggregate, the strongest and usually the most impermeable mortar is that which has the greatest density."

Before proceeding to the consideration of the application of these laws to the making of the most economical mixture of cement, sand, and aggregate for the required purpose, certain general rules can be given which are sufficient for small jobs.

The proportions of cement, sand, and aggregate are usually given as proportions by volume, the cement being measured as so many sacks of cement, and the sand and aggregate as so many cubic yards or cubic feet.

For small jobs the following figures and rules will be found useful, which are quoted from Taylor and Thompson.

Select the proportion of sand to cement for required strength, and add twice as much gravel or broken stone as sand.

A rich mixture for columns subjected to high stress, 1, 1½, 3.

A good standard mixture is 1, 2, 4.

A mixture for machine foundations, retaining walls, etc., is 1, 2½, 5.

Lean mixtures for large masses, backing of stone masonry, etc., is, 1, 3, 6.

It is obviously of importance to be able to calculate approximately the number of cubic yards of concrete obtained from a given quantity of cement, sand, and aggregate.

This will obviously vary according to the nature and grading of the materials, and elaborate tables and curves to enable close calculations to be made will be found in Taylor and Thompson; but for small jobs, if C = parts of cement, S = parts of sand, and G = parts of gravel, by volume, then the number of barrels (376 lbs. each) required for a cubic yard of concrete is $\frac{10{\cdot}5}{C+S+G}$, and of cubic yards of sand, $\frac{1{\cdot}55}{C+S+G}$, and of gravel, $\frac{1{\cdot}55}{C+S+G}$ (Fuller's rule).

The following table from Taylor and Thompson gives the tensile strength in lbs. per square inch which should be obtained from good mixtures:—

Cement.	Sand.	Gravel.	Lbs. per sq. inch.
1	1½	3	500
1	2	4	450
1	2½	5	400
1	3	6	360
1	4	8	290

A usual specification requires a graded aggregate, the largest particle to pass a 2-in. ring, or for smaller work, to pass a 1¼-in. ring. All particles to be larger than ¼-in. mesh.

Sand for Concrete.—Before considering in more detail the proportioning of concrete, it is necessary to begin by a careful consideration of the preparation of the cement mortar to which the aggregate is added. In the first place we shall begin by considering the quality of the sand. The selected sand should be carefully tested by being made up with the selected cement into test pieces and tested against standard sand. It is usually required in American specifications that a 1 to 3 mixture should equal in tensile strength a 1 to 3 mixture of standard sand, and if testing below 70 per cent. of the test for the standard sand mixture the material be rejected, and if testing above 70 per cent. the proportion of cement be increased till it equals the standard sand mixture in tensile strength.

The most dangerous impurity is organic matter. This can be tested for as follows: Wash with water, strain through 100-mesh sieve. Evaporate and weigh, then ignite and weigh. If the silt in the sand contains more than 10 per cent. organic matter, and if the organic matter is more than 1 per cent. of the total weight of sand, the sand should be rejected. The following chemical tests can also be made.

Test with hydrochloric acid for limestone contents. Test with 3 per cent. NaOH for change of colour due to organic matter; if a dark coloured solution is obtained, the sand should be rejected. The hardness and strength of the sand or fine aggregate is usually more than sufficient. The specific gravity can be determined by Jackson's apparatus, but the specific gravity of sand may be taken as 2·65 for purposes of calculation.

The following conclusions arrived at by Monsieur Feret, after exhaustive experiments, are of great practical value:—

(1) The sharpness of the sand grains is of small importance.

(2) The screenings from broken stones usually produce a stronger mortar than sand.

(3) Impurities in sand such as loam or clay, weaken a strong mortar but strengthen a weak mortar. In 1 : 2 mortar 2 per cent. of loam reduced the strength. In 1 : 3 mortar, 2 per cent. slightly increased the strength, and even 20 per cent. produced no appreciable injury. Ground terra cotta forms as strong a mortar as sand.

An excellent account of M. Feret's experiments on the effect on the strength of mortars of various blends of screened sands will be found in Taylor and Thompson.

THE GRADING OF SAND AND AGGREGATE

Before discussing further the proper blending of cement, sand, and aggregate to form the strongest concrete, it is necessary to consider carefully what happens when particles of various sizes are mixed together.

To begin with the simplest case, let us suppose a square box filled up with round balls of equal size. It is evident that even if packed in as carefully as possible there are unfilled spaces between the balls. If, for instance, the balls were made of paraffin wax, and a box filled with balls placed in a bath of boiling water so as to melt the paraffin wax, the space occupied by the melted wax would only be about 60 per cent. of that occupied by the balls.

If we look again at this diagram, it is evident that we could get much closer packing by having another set of balls of such a size as would enable them to go into the spaces between the large balls, and still closer packing by again having still smaller balls to pack into the tiny spaces between the big and the small balls. In fact, to get close packing we require a graded mixture, and not only so, but the closeness will depend in having it properly graded, both as to the size of the particles and the number of each size used. We can, if we like, regard a mixture of gravel and sand as such a graded aggregate, and the cement as a glue, sticking

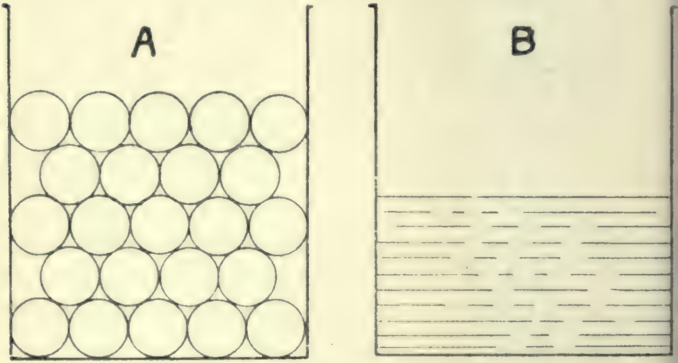


Fig. 11.—Voids in Aggregate.

the particles together, and from this consideration it is obvious that the better graded the aggregate the less cement will be required to make an equally strong concrete.

The matter, however, in practice, is not so simple as it might appear from this way of looking at it. In the first place, the finely ground cement itself may be regarded as part of our graded aggregate, and the addition of water and its combination with the cement further complicates the matter. In addition sand itself has a peculiar property which influences the result. Wet sand occupies a larger volume and weighs less than dry sand, the maximum increase of volume corresponding to about 7 per cent. of water, and in addition the increase of volume differs for different sands and different percentage of particles of varying sizes.

Such considerations might lead us to despair of any definite, simple rules governing the grading of aggregates, but fortunately experimental results have been obtained from which simple rules can be deduced.

Before explaining these experimental results, it is necessary to say something of the methods of grading, or as it is called, mechanical analysis.

For this purpose a series of sieves are used of increasing fineness, the sand or gravel being passed in succession through the sieves from the coarsest to the finest, and so separated into a series of samples, each of which contains particles too small to be stopped by the sieve above and too large to pass the sieve below.

Each of these samples are weighed, beginning with the finest, and placing each successive residue on the scale pan with that already weighed.

The following table taken from Taylor and Thompson illustrates the method from an actual case of the analysis of stone. The amount of crusher run taken was 1000 grams. The results were as follows :—

Size of Holes in Sieve in inches.	Amount finer than each Sieve in grams.	Size of Holes in Sieve in inches.	Amount finer than each Sieve in grams.
1·5	801	0·30	27
1·0	457	0·20	19
0·67	222	0·15	8
0·45	99	0·10	0

From these figures the percentages are calculated and plotted as follows :—

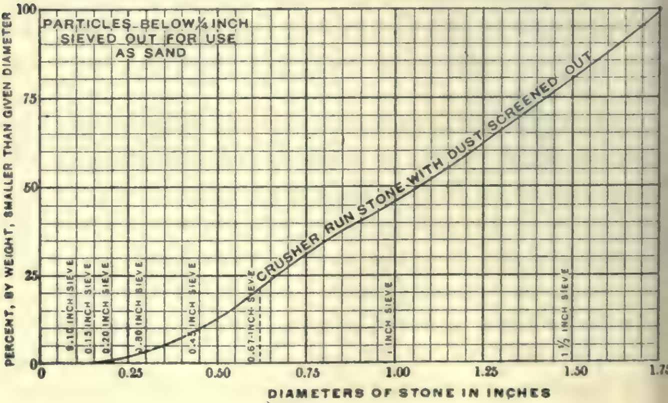


Fig. 12.—Typical Mechanical Analysis of Crusher Run Micaceous Quartz Stone.

The next question to be considered is how the compactness or "density" of a given mortar is to be ascertained.

This requires us in the first place to know the actual volume occupied by the mortar.

This is done by packing the mortar after gauging into a vessel of known dimensions but of a cylindrical shape. When the mortar has been mixed rather wet, it should be allowed to begin to set and the rest of the water poured off before taking the measurement. We thus obtain the total volume of the mixture. We next require to know the actual volume occupied by the dry sand and by the dry cement. This is easily obtained if both are weighed before mixing. Then it is only necessary to divide the weight of the cement by its specific gravity, and the weight of the sand by its specific gravity to obtain the volume of each.

For instance, suppose the total volume of the mortar to be 100 c.c., and the weight of cement in grams divided by its specific gravity to be 24, and of the sand divided by its specific gravity to be 50, then the actual volume of cement and sand in the mixture is $24+50=74$ per cent. of the total volume of the mixture.

Let C represent the percentage of the total volume in the mortar which is cement, and S the total volume of the mortar which is sand. Then for a given mixture of cement and sand the higher the value $C+S$ the stronger the resulting mortar.

Monsieur Feret in his experiments analysed the sand into three groups labelled respectively, F, M, and G. G passed 5 meshes to the linear inch and was retained on 15 meshes to the linear inch. M passed 15 meshes and was retained by 46. F passed 46 meshes. Monsieur Feret obtained his strongest mortars by excluding the medium grains and mixing the fine and coarse grains in the proportion of 2 of coarse grains to 1 of fine grains + the cement, and so finally arrived at the following approximate formula. If P be the compressive strength of the mortar, K a constant depending on the nature of the cement and sand used, then

$$P = K\left(\frac{C}{1 - S}\right)^2.$$

The importance of the investigation by grading of a sand before using it for making up a cement mortar is vividly brought out by the following table, taken from Taylor and Thompson, p. 162, and giving the results of some experiments of their own. In each case the mixture of sand and cement was 1 to 3, and the results are given with three sands, the gravimetric analysis of each being given :—

Sand.	¼-inch Sieve.	No. 8 Sieve.	No. 20 Sieve.	No. 50 Sieve.	No. 200 Sieve.	C+S.	Compressive Strength, 7 days.
1	100	84	62	28	3	·689	715
2	100	100	84	77	6	·620	405
3	100	100	92	84	27	·600	330

It is evident from these results that by proper grading of the sand a mortar of double the strength has been obtained from the same cement mixed with sand in the same proportion. The following graph, taken from Messrs Taylor and Thompson, p. 164, gives the analysis of two sands by Mr R. F. L. Humphrey in connection with the construction of Pennsylvania Avenue Subway, Philadelphia. The tensile strength of a mortar made from the one

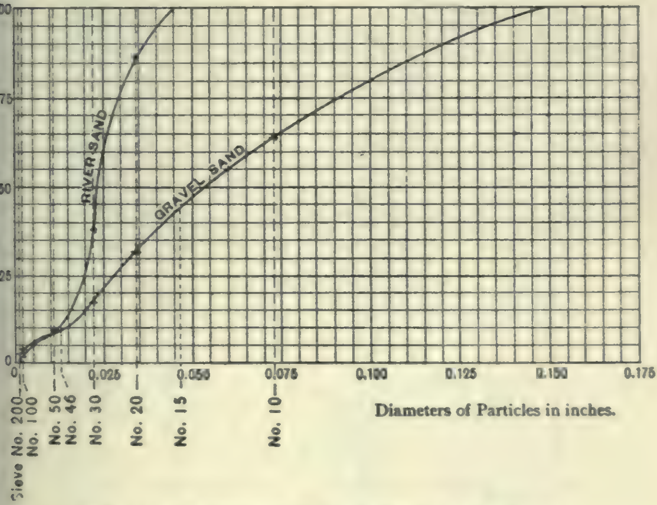


Fig. 13.—Conversion of Mechanical Analysis to Granulometric Composition.

sand is over 50 per cent. more than that made from the other.

A very elaborate series of experiments on sands from various sources, published by the Bureau of Standards (No. 58), show that the matter is not quite so simple as might appear from the above statement. It is evident that various sands have other properties

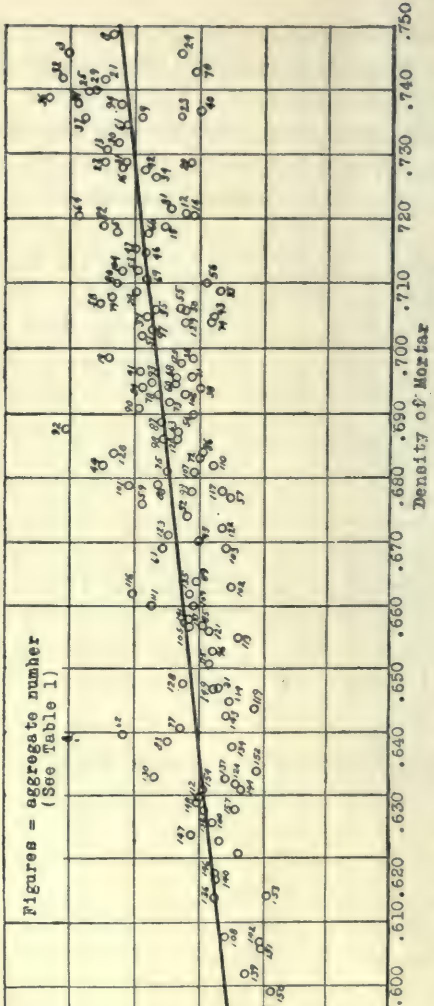


FIG. 14.—Relation of "density" or solidity ratio of Mortar to tensile strength. Age 13 weeks. Proportions, 1 part cement to 3 parts sand. The figured dots refer to different sands.

which effect the strength of the mortar. While therefore the density of the final mixture is one of the most important conditions, it is possible that a sand A may give a stronger mortar than a sand B which gives a denser mixture.

In practice sands from different sources should be tested to see which gives the strongest mortar, and mixtures of sands from different sources, and mixtures of the gradings of these sands. Considerable saving of cement will thus result by obtaining the blend which gives the strongest mortar, which will be found to approximate closely to the most compact mortar for a given sand.

The effect of introducing different proportions of crusher dust should also be tried.

Fine aggregates of limestone either in the form of sand or screenings produce a stronger mortar than ordinary sand.

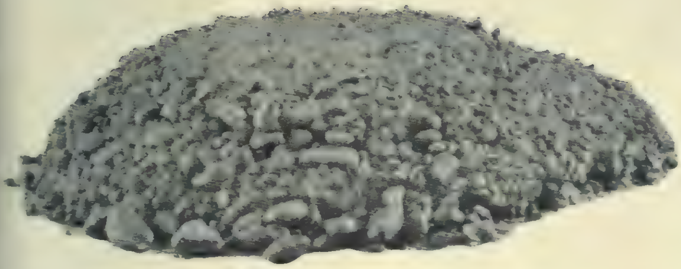
Having now dealt with the grading of cement mortar, we can next go on to deal with the grading of concrete. The same principle applies to concrete as to mortar, namely, that for a given percentage of cement and a given sand and aggregate the most compact concrete will give the best results.

To find the best proportion of an aggregate consisting of, let us say sand, gravel screened through revolving screens, or crushed screened stone, make up several mixtures and determine their actual volume by filling into a vessel of known dimensions. A complete mechanical analysis of the proposed materials should also be made and the effect tried of combining in different proportions. In general it will be found that the most compact aggregate will yield the strongest, or very nearly the strongest mixture.

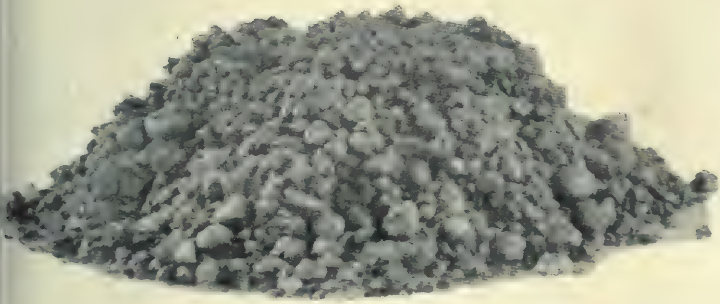
Mr Fuller, as the result of a large number of experiments, has arrived at the conclusion that for any aggregate the most compact and strongest mixture can be obtained, by so grading the material as to make it agree with an ideal mechanical analysis curve which is a combination of a straight line and an ellipse.

For a full description of the application of this method the reader is referred to Taylor and Thompson, p. 191, Third Edition, and for a discussion and criticism of Fuller's conclusions to the Technological Papers of the Bureau of Standards, No. 58. Among other recent literature the reader may consult the *Engineering News Record*, 1st January, p. 33, where will be found an account of the methods of Professor Abram and Mr Edwards, based upon a study of the surface areas of the aggregate and of the ratio of water to cement, and a criticism of their conclusions published by the Bureau of Standards.

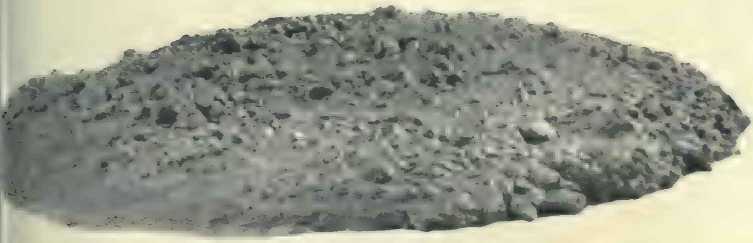
It is evident that much more research is required before the exact condition for obtaining the strongest concrete from the smallest proportion of cement are thoroughly understood, a matter of increasing importance with the increasing cost of cement. At the same time it has been conclusively shown that careful experiments, accompanied by a mechanical analysis of different possible sands and aggregates, should be made to find the most economic mixture, and that roughly the densest mixture is usually the most economical.



Mushy consistency.



Quaking consistency.



Fluid consistency.

Fig. 15.—Appearance of Gravel Concrete of the three consistencies used in these tests and described on page 87. Taken from the Bureau of Standards Report, No. 58.

[*Face page* 86.

Proportion of Water Used.—The experiments published by the Bureau of Standards, No. 58, show the great effect on the strength of the concrete of using too little or too much water. The best results are obtained with a concrete of a quaking or mushy mixture. If anything, the water should be slightly below this amount. A quaking mixture is defined as a stiff mixture upon which water can be brought to the surface by slight tamping. A mushy mixture is a mixture which is not watery, but can be spaded and readily worked into place in the form when concrete is being cast into blocks. It should contain the maximum of water possible to enable it to be removed from the moulds, if its compressive strength is of importance.

In conclusion, too much care cannot be given to the mixing and placing of concrete, if the best results are to be obtained. On the whole machine mixed concrete usually gives a higher test than hand mixed. Concrete should be kept wet for several days or weeks if the maximum strength is to be obtained.

Action of Sea-water.—It was supposed at one time that the injurious action of sea-water on concrete was due to the action of magnesia in solution in the sea-water. It is now known to be due to the action of sulphates in the sea-water.

A sulphate in solution, whether from the presence of sulphate of magnesia in sea-water or sulphate of lime in solution in water percolating through the concrete, combines with the aluminate of lime in the cement to form a double sulpho-aluminate, which swells and disintegrates the cement. This seems to be the main cause of trouble. For this reason cements should be used low in alumina, which may be replaced by iron in combination with advantage. Excess of lime is also dangerous, and the cements are consequently improved in their power of resisting sea-water by the addition of Puzzuolana or similar material.

Freezing of Cement.—Care should be taken to protect cement mortar from freezing during cold weather. Salt, glycerine, and alcohol have all been used for this purpose. Professor Tetmajer's rule requires 1 per cent. of salt to the water used for each degree Fahrenheit below freezing.

Waterproof Concrete.—In order to ensure that the concrete be waterproof, a fairly rich mix should be used and the sand and aggregate properly graded, and the concrete be laid of quaking consistency and all joints avoided. Grouting or careful trowelling makes it more waterproof. It may also be treated with paraffin wax driven in by heat, or with alternate soakings of alum and soap. The addition of slaked lime (thoroughly fine and completely hydrated), or of finely ground burnt clay, makes it more waterproof. Layers of asphalted paper or felt are sometimes introduced.

Permeability Tests.—Various mortars and concretes can be tested for permeability by finding the amount of water passed in a given time through a block of given dimensions, with the water at a given pressure. A description of the apparatus used and results obtained will be found in Taylor and Thompson, p. 306.

Modulus of Elasticity of Concrete.—Earlier in the book the formula for calculating the modulus of elasticity was given. The determination of the modulus of elasticity is surrounded by many difficulties; for a 1, 2, 4 mix it may be taken as E = 2,000,000 lb. per square inch.

CHAPTER V

BRICKS

THE bricks ordinarily used for building purposes are made from clay or shale, which is made into the required shape and then baked at a bright red heat in a kiln.

The chemical composition and the history of formation of china clay have already been discussed. It is a hydrated compound of silica and alumina produced by the decomposition of felspar. Ordinary clay contains in addition compounds of iron and other materials, and has been produced by the disintegration of various rocks containing felspar or other alumina silicates. The smaller particles have subsequently been carried off in a current of water, leaving the coarser ones behind. The small particles were gradually deposited in the beds of rivers, lakes, or seas, and after being again suspended in water and redeposited—this treatment being repeated many times—have eventually reached their present site and form beds of a complex mixture known as clay. During the complex changes which most clays have undergone since their original formation, their physical properties have greatly changed and the "true clay" in the material has become plastic. That is when kneaded with water it can be pressed or moulded into any shape, and retain that shape after the pressure or mould has been removed. This property of plasticity is possessed by some other materials, but in the case of clay it is peculiarly valuable because it can be imparted to a mixture of clay and sand, so that the whole mass is rendered plastic and suitable for the manufacture of bricks, pipes, pottery, and other articles used in building.

The physical and chemical conditions necessary to produce a plastic material are somewhat obscure, but it is known to be associated with the state of the clay particles which enables them to form a colloidal or gelatinous coating over the particles of sand and inert manner, uniting the latter with a flexible cement of considerable viscosity. Pure clay—even when wholly colloidal—is only feebly plastic as it requires the presence of inert grains of sand or the like before a highly plastic mass can be produced. As plasticity is so closely related to the colloidal state, any method of treating a natural clay which will increase the amount of colloidal gel or flexible cement present and distribute it properly among the inert particles, will also increase the plasticity of the material as a whole. Conversely, any treatment (such as drying or heating) or any addition of a non-plastic material (such as sand) will reduce the plasticity of a clay mixture by either destroying some or all of the colloidal matter, or by diluting it so that it is distributed throughout more material than that to which it can give a maximum of plasticity.

It is not profitable to increase the plasticity of feebly plastic materials for use in brick manufacture by the addition of "chemicals" such as tannin infusion, but it is possible to develop latent plasticity by adjusting the amount of water present, and by distributing the materials more uniformly through the mass by the use of mechanical mixers.

Clays which are excessively plastic are not suitable for making bricks, etc., until they have had their plasticity reduced by heating or (more usually) by the addition of a cheap diluent such as sand, chalk, coke dust, "grog" (brick dust), or even crushed rock or ashes.

The chemical composition of the crude clays used for building bricks is of minor importance, but their physical properties are highly important. A suitable "brick earth" must be sufficiently plastic when mixed with water to form a paste of such consistency that it can readily be moulded or expressed through a machine resembling those used for making sausages. The bricks, when made, must be capable of being dried fairly rapidly by artificial heat, without cracking or distortion, and the burned or baked bricks must not have twisted or warped as a result of an excessive amount of fusion of some of the particles present.

Stones and gravel, when present in a bed of "clay," may be harmless or destructive according to their nature. Purely siliceous stones may be reduced to sand by suitable crushing appliances (though this may add so much to the cost of manufacture as to make the production of bricks unprofitable). Limestone, on the contrary, is highly detrimental unless every particle present does not exceed $\frac{1}{50}$ in. in diameter. In highly plastic mixtures it is extremely difficult to reduce limestones to such a fine state, so that "clays" containing lime in the form of stones and gravel should usually be avoided by brick manufacturers.

The pieces of limestone are converted in the kiln into quicklime, which slowly slakes when the bricks are exposed to air. During this slaking, the lime doubles its volume and in doing so exerts a pressure which is sometimes so great as to split the brick. The presence of quicklime in the finished bricks is readily detected as it forms white spots of soft material which responds to the usual tests for lime. For the effect of chalk see "White Bricks."

The red colour of some bricks is due to iron compounds present in the "clay" of which they are made, but it is by no means certain as to which compound of iron the colour is due. It is commonly, but probably erroneously, attributed to the red ferric oxide. Many attempts to improve the colour of bricks by incorporating ferric oxide or solutions of iron salts with the raw clay have proved to be complete failures.

White Bricks—especially those made in Suffolk—are composed of a natural or artificial mixture of red-burning clay and chalk. The latter enters into combination with the iron compounds in the clay, forming a white product if sufficient chalk is present or pink or salmon-tinted bricks if there is a deficiency of chalk.

It is important to observe that chalk—consisting as it does of very minute particles—can be so thoroughly incorporated with the clay that it does not cause disintegration of the bricks, and so differs from the larger particles of limestone mentioned under the caption "stones and gravel." If the chalk is insufficiently distributed it will cause the defect just mentioned.

Selection of Clays.—The satisfactory selection of a clay for brickmaking is so difficult and involves so many complex problems of geology, chemistry, and physics, as to make it most desirable to consult an independent expert. No brickwork's foreman, no salesman of brick machinery or kilns, and no ordinary analyst or general geologist has either the knowledge or special facilities for this work, and many of the most serious failures in the past history of brickmaking have been due to the choice of unsuitable material, or of a process of manufacture ill-adapted to the available "clay." Whilst, therefore, the prospective brick manufacturer should always obtain skilled professional advice before commencing or even purchasing a brickyard, the following notes on the characteristics of some well-known types of clay should be familiar to all students of building materials.

Pure Clay does not occur in Nature, and the clays used for brickmaking frequently contain only half their weight of pure clay. Hence the use of the term "clay" for such crude mixtures is misleading, and the term "brick-earth" is therefore more suitable to describe the raw material used for making bricks. Unfortunately, many brickmakers confine this term to superficial deposits found in the south and south-east of England, and specially suitable for handmade bricks. River-deposited "clays" are often good for brickmaking, but are liable to be very irregular in composition. Clays which have been deposited at the bottom of lakes, or under a prehistoric sea, are usually more uniform and often form most valuable brickmaking materials. Clays which have been carried over long distances by glaciers, *e.g.*, "boulder clay," are very widely distributed in these islands. They vary greatly in character from a highly plastic clay or till to an almost useless mixture of clay, pebbles, and limestone dust. The most serious objection to glacial clays is the limestone gravel which is present.

Marls are natural or artificial mixtures of chalk and clay, but the term is also applied to "dry" friable earths which are destitute of chalk, and is therefore misleading unless accompanied by some further information. The term malm is restricted to mixtures of chalk and clay.

Loams—in the sense in which this term is used by brickmakers but not by gardeners—are natural mixtures of sand and clay, which possess a moderate amount of plasticity and are usually suitable for brickmaking. If a loam is very rich in sand, the bricks made from it will be so friable that they may readily be rubbed or cut into special shapes for arches, closers, etc. Such bricks are known as rubbers and cutters respectively.

The older clays which have been subjected to great natural pressure since their deposition, and have formed a laminated mass, are known as shales; when ground with water many of them recover sufficient plasticity to be useful for brickmaking.

Shales usually contain a certain amount of organic matter; those near Peterborough, from which the Fletton bricks are made, contain so much of it that they require only about one-eighth of the coal used for burning other clays.

The tips of shale and other "refuse" at the coal-mines usually contain a certain amount of coal intermixed with clay and rock. Such a mixture, if carefully selected, may be quite suitable for brickmaking. Sometimes, however, the amount of coal present is so large that it is difficult to burn the bricks sufficiently slowly or to control the burning properly unless special kilns, or unless the greater part of the coal is removed by a process of washing before making the material into bricks. Some of the shales near Edinburgh contain so much organic matter in the form of petroleum that they are useless for brick manufacture, but are mined and distilled so as to recover their petroleum contents.

The fireclays are relatively free from impurities. The main deposits are associated with the Coal Measures. The chief value of bricks made of fireclay is their great resistance to heat which enables them to be used in the construction of furnaces, etc., for which common building bricks—being too fusible—would be useless. Special care is required in selecting firebricks, as it is useless to employ bricks of a porous nature, but great heat-resistance in those parts of a furnace where the chief demand is for resistance to slag or abrasion, or to use dense bricks of low heat-resistance where highly refractory bricks are required. As the subject of firebricks is large and complex, the reader desiring further information should consult *Refractory Materials, their Manufacture and Use*, by A. B. Searle.

The oldest type of brick is the sun-dried brick, which is made by moulding a plastic paste to the desired shape and drying the bricks, first in the shade and then in full sunlight. A similar use of plastic earth or clay without baking has been used for centuries in the construction of the cob houses in Devonshire and Leicestershire, and the "mud huts" of other countries. It has recently been revived in this country under the name of Pisé de terre.

The process of drying—even in open sunlight in a tropical country—removes the water from the bricks, converting the cementitious matter formed by the colloidal clay into a hard, hornlike material. On exposing such dried material to water, some of the latter is absorbed and the mass falls to pieces or "slakes" in a manner similar to quicklime when similarly treated. Hence, sun-dried bricks are not very durable in a damp climate, though if protected with a rough cast coating of cement-mortar they will last for many years.

The durability of bricks which have been properly heated in a kiln is so great that it cannot be measured. During this heating, the clay is decomposed and a different material—too complex to be described here — is produced. By no means now known can such baked or burned clay be wholly reconverted into its original plastic state, though trifling amounts of plastic material can be produced by prolonged heating in the presence of dilute alkaline solutions under a very high pressure. This extraordinary resistance of burned clay (even when relatively impure as in the case of building bricks) to all ordinary conditions is one of the chief reasons for the great value of bricks, terra-cotta, etc., as building materials.

The process of burning is never complete, but the heating is stopped as soon as the bricks have gained the desired characteristics. For common bricks it is merely necessary to continue the heating at a bright red heat until the true clay present is completely decomposed and sufficient fusion has occurred to enable the non-plastic particles to be strongly united by a crude, fused glass or slag. Where much stronger bricks are required, as for engineering purposes, or where they are to resist abrasion and corrosion, as in stable- and paving-bricks, the heating must be continued under conditions which will ensure the production of sufficient fused material to fill the whole of the pores with a glass or slag, yet without causing distortion or loss of shape in the brick as a whole. The extent to which fusion has occurred may be judged by the note emitted when two bricks are struck together—good bricks emit a clear ringing sound—and by the amount of water absorbed by the brick. Underburned bricks are highly porous and readily crushed;

over-burned bricks are devoid of porosity and are, usually, badly distorted.

London Clay is a good example of a clay which will not make bricks when used alone, as it is too sticky and shrinks so much that only a small proportion of the bricks remain whole during the drying. In order to overcome this defect the London clay is only worked in localities where it can readily be mixed with cinders, reducing the plasticity of the clay in order to make a brick which will dry without shrinking and cracking, and also increasing the strength of the burned brick. The cinder-dust keeps the brick material porous and also acts as a fuel. In this way, the mixture of a comparatively useless clay or earth with suitable materials, makes excellent bricks admirably suited for the very trying conditions of the climate of the Metropolis. London stock bricks are made of natural mixtures of clay and chalk known as marls, or of artificial mixtures of these materials. The mixture is mixed with "soil," *i.e.*, dust obtained by sifting domestic ashes. These bricks are usually burned by stacking them one above another with layers of small cinders (termed breeze) between them, the bricks in each course being about $\frac{5}{8}$ in. apart. The stack or clamp, when completed, is covered with burned bricks so as to form an air-tight casing, in which are provided inlets for air and outlets for the products of combustion. Fuel is placed in troughs arranged in the lower part of the stack, and when once this is lighted the burning proceeds automatically if the clamp has been properly built. The arrangement of the bricks is complex and cannot be described briefly; in fact, clamp-burning is an art requiring a very considerable amount of skill.

Pressed Bricks are, as their name implies, made in a press. Hand-moulded bricks are made by throwing the paste into small moulds. Wire-cut bricks are made by cutting a horizontal column of stiff clay paste about 9½ in. wide and 4¾ in. deep cross-wise by means of a series of wires stretched on a frame, 2½ to 3¼ in. apart. Bricks are also known by various names according as they are made from a soft paste (soft-mud bricks), a stiff plastic paste, or from a semi-dry material of the consistency of good garden soil.

Facing Bricks are those used for exterior work, their colour and shape being very important. Common bricks or stocks are bricks suited for general use, their colour and appearance being of minor importance, though the use of this term varies in different parts of the country. Probably the best general definition of a stock brick is one which represents the average production of any given brickyard. Hence, a stock brick in Lancashire is entirely different from a London stock brick, being made from a different material and in a different manner. Various other special names are used for bricks; for further information on these a larger treatise, such as *Modern Brickmaking*, by A. B. Searle, should be consulted.

The Preparation of the Clay.—In former days the clay or earth to be used for brickmaking was usually dug in the summer and left in heaps, so that during the winter it was exposed to the action of frost and rain. By weathering it in this way, the stones and gravel could be more readily seen and picked out, and the clay was more easily reduced to a suitable paste in the mill; at the same time its plasticity was slightly increased. This method of treatment is still used for many clays; but under the stress of modern manufacturing conditions more powerful mechanical means of crushing the earth are used, and the old and slow methods of treatment tend to disappear. This is unfortunate, as a clay or earth which has merely been crushed is quite different from one which has been properly weathered.

Shales and hardened clays must usually be quarried by the aid of explosives, but the softer earths may be dug with a spade or by means of a steam navvy.

The treatment of the crude clay thus obtained must depend on its nature. If it contains injurious stones or gravel it must be washed, *i.e.*, mixed with several times its volume of water and stirred until it forms a liquid slurry. This is allowed to remain stationary for a few moments during which the stones and gravel settle; the clay and water are then run off into large tanks or ponds where the clay gradually settles and the supernatant water is then run off. Washing is also used when clay is to be mixed with chalk, as a more thorough incorporation of the two materials is obtained by mixing the slurries than by any other method.

When the clay or shale does not need any purification, it may be sent direct from the quarry to the crushing or mixing machines wherein it is mixed with water and converted into a paste of suitable consistency, this operation being known as pugging or tempering.

Shales are sometimes ground to a coarse powder, screened to separate the coarse particles, and then pugged or else passed at once to a press. Plastic earths cannot be reduced to powder without previously drying them; they are therefore passed direct to a pugmill or first between crushing rolls and then to the pugmill.

After separation of stones from the clay, the clay may be washed and allowed to settle in large settling ponds, from which it is subsequently dug, or it may be ground and used directly for brick-making. There are many varieties of preliminary treatment depending on the nature of the material. It can also be mixed with the other ingredients already mentioned when necessary.

After grinding, the clay is "tempered" by mixing with water. It should be left mixed with water for some two or three days before it is "pugged" in the pugging mill by which it is thoroughly mixed. It is then ready for making into bricks.

Shaping the Bricks, Hand-Moulding.—The oldest process—which is still in extensive use—consists in moulding the bricks by hand. In slop-moulding, the mould—which consists of a frame the size of a brick—is wetted with water prior to filling it with the clay paste. In sand-moulding, the mould is first sprinkled with sand which covers the whole of its interior. Both the sand and water are used to prevent the clay adhering to the mould, but the use of a suitable sand has the advantage of producing bricks of a fine rich red colour and a pleasing rough texture which make them in great demand as facing bricks. Clays which, naturally, have a pleasing colour when burned, and those in which the colour is unimportant may be slop-moulded. After the mould has been filled and any surplus clay removed, the mould is dexterously emptied on to the drying floor or on to a small board on which the brick is carried away to be dried. Hand-made bricks are often allowed to stiffen slightly, after which they are pressed in a pressing machine operated by either hand or power.

Plastic Moulding.—As hand-moulding requires great skill and is very hard work, it is difficult to obtain sufficient moulders. Consequently, various mechanical devices have been brought into use. Some of these machines fill moulds similar to those used in hand-moulding (stiff mud process), in others the clay paste is forced through a suitably shaped die or mouthpiece, the resulting column of clay being then cut transversely by taut wires (wire-cut process). The bricks made by either of these processes may be allowed to stiffen slightly, and may then be repressed where a good quality of facing brick is required and the material is suitable.

In all plastic processes of making bricks the product is too soft to be sent direct to the kiln, and the bricks must therefore be dried either in the open air in long rows called hacks, or in drying rooms or tunnels which are artificially heated.

In the most economical form of drier, the bricks are placed on cars which pass slowly through a long tunnel, the conditions in which are such as to dry the bricks as rapidly as possible with a minimum of waste. In the best tunnel driers even the most delicate clays can be dried in forty-eight hours and others much more rapidly, whilst on a hot floor three days will be required, and the drying in the open air is seldom completed in less than three weeks. The hot floor system of drying is cheaper to instal than a tunnel, but the cost of placing the bricks on the floor and picking them up again to take them to the kiln makes it more costly in labour than the tunnel drier. Moreover, the conditions in the tunnel are under far better control.

Bricks are much more tender than would be supposed by those unacquainted with them in the plastic state, and great care and skill are required in drying them successfully and rapidly.

"Stiff Plastic," "Semi-Plastic," and Semi-Dry Processes.—In order to save the time and fuel required for drying, bricks are largely made from shale and indurated clays by means of powerful grinding machinery which reduces the material to powder, which is then mixed with very little water, or without any water at all, and the product is passed into steel moulds wherein it is shaped mechanically under a very considerable pressure.

According to the amount of water used and the consequent consistency of the material, this method of shaping is known as the stiff-plastic and semi-plastic processes or semi-dry, the former term being applied to a very stiff, plastic paste, and the two latter to a damp powder of the consistency of moist garden soil or wet sea sand.

The stiff-plastic process can deal with many natural clay-earths and shales, and the bricks produced by its means are among the best now made. The plasticity of the clay is developed sufficiently to produce the required cementitious effect, and such bricks are preferred by many architects and builders to those made of a drier material.

The semi-dry process (the term semi-plastic is a misnomer and should be abandoned) is the one used in the manufacture of Fletton bricks. It is cheap and effective, but is limited to certain materials. To be profitable it must be worked on a large scale, and it is not at all suitable for the many small yards scattered about the country.

For further details on these various processes, the larger treatise by Searle on brick manufacture should be consulted.

Each of these various processes of brickmaking is suitable for a particular variety of "clay," and to obtain the best results the machinery should be selected, so as to be thoroughly suitable for the material available. It is a serious mistake to select a process and to try to adapt the clay to it, and many commercial failures have resulted from this procedure. It is true that satisfactory bricks can be produced by any of the processes described; but if the production is to be commercially profitable, it is necessary for clay or shale suitable to the process selected to be available or readily adapted so as to make it suitable. Here again, as in the selection of a clay, the assistance of a professional technologist who is independent of all makers of machinery or builders of kilns is invaluable.

The Firing of Bricks.—Bricks may be baked, burned, or fired in a "clamp," or in one of the many patterns of up- down- or horizontal draught kilns either of intermittent or continuous type.

When burnt in a "clamp" they are arranged as described under London stocks. Clamp-burning is cheap, but the quality of the bricks is very irregular and there is a great deal of waste.

Intermittent kilns consist of a single chamber containing the bricks to be burned, and heated by a series of fireplaces in the walls of the kiln. The flames and hot gases pass into the interior of the kiln and rising upwards (up-draught), downwards (down-draught), or passing horizontally towards the other end of the kiln, mingle with the bricks, heating them, and then pass to the chimney. As the gases enter the chimney at a temperature almost equal to that of the bricks, single kilns are very wasteful in fuel. Bricks burned in up-draught kilns are similar in many respects to clamp-burned bricks. Bricks burned in down-draught kilns are usually of much better colour and pleasing appearance. The horizontal kilns are chiefly used for firebricks.

Continuous kilns have the advantage of being very economical in fuel, and only use 25 to 50 per cent. of that required in single kilns. Most of the best known types of continuous kiln are based on one designed by F. Hoffmann in 1871, in which the surplus heat from one portion of the kiln is used to heat a further supply of bricks, whilst air drawn over the finished bricks, so as to cool them, is, in its turn, heated to a high temperature and so effects the combustion of the fuel under the most favourable conditions. The plan of the original Hoffmann kiln is that of a circular tunnel with the chimney in the solid brickwork at the centre of the circle. Access to this tunnel is gained by a series of openings, all but one of which are closed during firing. The tunnel is divided by a series of imaginary partitions and one actual one into a series of chambers, and each of these is heated in turn, just as in a similar series of separate kilns. As the chambers are connected with each other, however, the gases pass forward heating the bricks to be burned, and so avoiding the loss of heat escaping to the chimney in single kilns. Under normal conditions, one "chamber" is emptied and another is filled daily, so that the fire travels round and round endlessly, the heating and cooling of the bricks being quite continuous. In more recent modifications, the shape of the kiln has been altered into two rows of chambers with connecting flues at each end, and for bricks, etc., in which colour is important, actual partitions and special fire-grates and flues for controlling the air-supply and for completing the drying of the bricks are used. The "Staffordshire" kiln is a good example of a kiln of this latter type, and is used for producing fine qualities of facing bricks and terra-cotta. The chief patterns of kiln—of which there are over 400 British patents—are described in *Kilns and Kiln-building*, by A. B. Searle.

The heating of kilns containing bricks to be burned should be very carefully controlled. The temperature should rise very slowly at first so as to decompose the true clay, and secure the removal of the water thereby liberated, without damaging the bricks. This decomposition is completed well below a red heat, and afterwards the temperature may rise more rapidly. It must not be too rapid, however, or fusion of some of the particles will occur before the organic matter has been burned out of the brick and this will leave black cores or "hearts"—a clear sign of unskilled burning.

The finishing point of the burning must be determined by the qualities required in the bricks. For inside purposes, where the lowest quality of bricks will suffice, it may be considered sufficient to heat the bricks to a moderately bright red heat, no attention being paid to the actual temperature or to the amount of shrinkage. Such bricks are merely baked; they are very porous and of moderate strength. Rubbers and cutters are of this character, as if heated more strongly they could not so readily be rubbed or cut to the desired shapes.

For most purposes, where colour is not important, the bricks should be heated so as to form sufficient fused material to produce, when cold, really strong bricks. The longer the heating, provided the temperature is sufficiently high, the stronger will be the bricks, as they will contain a correspondingly larger proportion of fused material. The heating must, of course, cease before the bricks lose their shape. If the later stages of heating are conducted with an insufficient supply of air, any ferric compounds present in the clay will be reduced to the ferrous state and will immediately form a black and readily fusible slag of ferrous silicate. This slag fills some or all the pores in the brick, and when the latter is cooled an exceedingly hard and strong brick—equivalent to the famous Blue Staffordshire bricks—will be produced. In these, as in other bricks, the strength is due to the cementing action of the solidified fused material.

When the colour of the bricks is of chief importance the burning must be controlled accordingly, and the heating may have to be stopped at a stage where the colour is good whereas, by prolonged heating, stronger bricks yet with an unpleasant colour may be produced.

Properties of Bricks.—A well-burned brick should be uniformly coloured throughout. It should not be black in the centre whilst red externally. It should "ring" when struck, and should be free from cracks and other flaws.

Insufficiently burned bricks, except rubbers and cutters, when struck together emit a dull sound and are not so durable as those which have been properly burned, *i.e.*, raised to a temperature sufficient to produce incipient vitrification.

Staffordshire Blue brick and bricks used for paving —in which the vitrification or partial fusion is pushed further than in ordinary building bricks—

have a very high crushing strength for the reasons given. Such bricks are difficult to produce as the whole process of "blueing," *i.e.*, of forming the ferrous silicate, requires great care and skill.

Bricks which are over-burned are usually misshapen, owing to the production of an excessive amount of fused material.

Testing Bricks.—Bricks may be tested for their resistance to crushing. It is also usual in America and on the Continent to test some engineering bricks by determining their modulus of rupture when they are tested as beams, supported at each end and weighted in the centre. The formulæ already discussed apply to these tests.

For paving bricks an abrasion test is applied in the United States and occasionally in this country.

Bricks may also be tested for their power of water-absorption, *i.e.*, the weight of water retained when the brick has been immersed in water, withdrawn, wiped dry, and then reweighed. The increase in weight should not exceed 15 per cent. The resistance of bricks to alternate freezing and thawing, and to the effect of immersion in a saturated solution of sodium sulphate in water also affords valuable information as to their durability under trying conditions.

Another instructive test is to place a series of bricks on end in shallow dishes of water, after keeping them for some days in a room at ordinary temperatures. The rate at which the water rises towards the top of the brick is then observed.

As in the case of stones, the crushing strength of an ordinary, sound brick is far beyond any load which it has to maintain in an ordinary building. The extent to which the weathering properties of a good brick can be safely judged by its water-absorption and resistance to freezing is open to considerable doubt; these tests only serve to distinguish the worst bricks.

Most good bricks, including London stock bricks, are practically imperishable even in London, but some bricks made by the semi-dry process soon perish. Facing bricks are selected principally for their appearance and fine colour, but due attention should also be paid to their mechanical properties.

London stock bricks stand a crushing load of from 100 to 180 tons per square foot; Rubbers from 30 to 60 tons; and Staffordshire Blue bricks from 380 to 460 tons.

Sand-lime Bricks.—Sand-lime or lime-sand bricks are made by mixing sand with 6 to 10 per cent. of lime and a little water into a paste, pressing this under a hydraulic or mechanical pressure of about 200 tons on the surface of the brick, and then exposing the brick to steam at high pressure or to superheated steam at the same temperature for several hours. Bricks made with sand, or in which the sand is replaced by granulated blast-furnace slag, clinker, or burned shale, have been very largely used on the Continent for many years as a building brick, the yearly output in Germany alone before the war being about 1,500,000,000 bricks a year. They have also found favour in America and, if properly made, are very durable bricks which withstand the weather well.

Their manufacture in these islands has been comparatively limited in the past owing to the widely distributed supplies of building stone and of brick earth. The shale heaps from the distillation of petroleum shale in the Lothians of Scotland are now being utilised to manufacture this type of brick. Full details of their manufacture is given in *Bricks and Artificial Stones of Non-Plastic Materials*, by A. B. Searle.

Glazed Bricks.—Bricks may be glazed either by the usual process adopted for other glazed ware, namely, the application to the surface of the bricks of certain easily fusible silicates mixed with suitable pigments which are afterwards fused by heating the bricks in a kiln, or by introducing salt into the fireplaces of the brick kiln during the last stage of burning. This produces a very durable glaze.

The Crushing Strength of Brickwork.—As stated above, the crushing strength of a brick is very much higher than any load it has to carry in ordinary buildings, but the crushing strength of a brick pier or wall is very much less than that of the individual bricks of which it is composed. As an example of the difference, the following experimental results may be quoted from Johnson's *Materials of Construction*.

The bricks selected had a modulus of elasticity of 4,000,000 and a crushing strength of 14,000 lb. per square inch. These were built to form columns 6 ft. to 10 ft. high and 12 in. square.

When lime-mortar was used 1 : 3, after the pier was from eighteen months to two years old, the modulus of elasticity varied from 250,000 to 750,000 lb., and the crushing strength from 700 lb. to 1300 lb. per square inch.

With Portland cement mortar, the modulus of elasticity rose to 3,000,000 and the crushing strength to 2,500 lbs.

It is evident from these results that the crushing strength of a brick column made with ordinary mortar is less than 10 per cent. of that of the brick itself, while even with Portland cement it is less than 20 per cent. of that of the individual bricks. These results have been generally confirmed by tests made at the National Physical Laboratory and elsewhere.

CHAPTER VI

TERRA-COTTA, PISÉ-DE-TERRE, ASBESTOS

Terra-Cotta.—Terra-cotta is the term applied to baked earth made up into blocks, pottery, etc. It is usually confined to unglazed ware, but within the last twenty years "glazed terra-cotta" has been extensively used as a substitute for stone as a building material, particularly in industrial centres.

Terra-cotta may be regarded as a superior form of brick-work, the pieces being much larger and frequently ornamented by modelled or carved work. A moderately soft paste is made in the same manner as for bricks—a superior clay being used for the purpose—and this paste is shaped either in moulds or by modelling with wooden tools. The articles thus produced are dried and then fired in kilns in such a manner as to protect the surface of the ware from discoloration by flames, etc., the whole process of manufacture being closely allied to brickmaking but requiring more skill and care.

When glazed terra-cotta is to be made, it is first shaped as described above and when dry is covered with a slip or cream composed of the finely powdered glazing materials and water. Sometimes a jelly, made of the same materials together with a little gelatin, is preferred to the liquid. When the coating of glaze is dry, the ware is placed in a muffle kiln and fired to a temperature sufficient to bake the ware and to cause the glaze to melt and distribute itself uniformly over the surface to which it is applied.

The chief precautions required in the manufacture of terra-cotta are those which will enable all the pieces to be of exactly the size and shape required (due allowance being made for the shrinkage in drying and firing) without distortion, and to possess the required colour. The ware must be protected from flame and condensed vapours whilst it is in the kiln, and it must be dried under rigidly controlled conditions. Terra-cotta cannot be cut after it has been fired, without spoiling it, so that the greatest care is necessary to keep all the pieces accurate in size and shape.

Roofing Tiles.—Roofing tiles form a particularly durable and convenient roofing material, which has the advantage over slates of being capable of production in a much greater variety of shapes. Roofing tiles range, in fact, from the plain rectangular shape about 11 in. by 7 in. through the curved pantiles so largely used in country districts, to the very elaborate interlocking tiles so extensively used abroad and to a smaller extent in the Southern Midlands and West Country. The simpler forms of tiles are fastened to the roof timbers by nails or by projecting pieces on the tiles (known as "nibs"); the curved or corrugated tiles and pantiles are of such a shape that they keep each other in position, and the more elaborate interlocking tiles have many ingenious arrangements which prevent them moving out of place even in the strongest winds. Unfortunately, interlocking tiles make a very heavy roof, but it is very effective in every respect.

Tiles are usually made by moulding a clay paste, though some are made in the same manner as wire-cut bricks by expressing the paste through a die and cutting the resulting column into suitable lengths. They are burned in kilns in a manner similar to bricks, but require more care in placing them in the kiln and in controlling the burning.

As tiles are required to fit closely together, it is essential that they should be made from a material which will not distort unduly during manufacture, particularly in drying. Consequently, whilst they are made from similar clays to those used for bricks, many brick earths are unsuitable for tiles. Considerable skill and experience is also needed in designing new patterns of tiles, as it is easy to produce tiles which look effective but will not form a water- and wind-proof roof.

For the junctions to different parts of adjoining roofs, special tiles known as "hips" and "valleys" respectively are used according as the joint is convex or concave. Along the top or ridge of a roof convex tiles, somewhat resembling a half-pipe and known as ridge-tiles are employed, and at the end of the ridge or surmounting conical roofs there is sometimes an ornamental finial of terra-cotta moulded or modelled to represent a dragon or other fantastic device. These finials are made in the same manner as terra-cotta.

Sanitary Ware.—No modern house is complete without adequate sanitary fittings, and for these no material is so suitable as porcelain, stoneware, and glazed fireclay ware. For most purposes, porcelain is too costly, stoneware is extensively used, and earthenware made of a fine body is employed to a moderate extent; but most of the white ware sanitary fittings now in use are made of fireclay which has been covered with a coating of a white earthenware nature, and then by a leadless glaze composed chiefly of felspar or china stone. Such ware is made from a paste made by grinding the fireclay to powder and mixing it with water, the paste being then shaped by pressing it into plaster moulds. Some of these moulds are made of many pieces, and considerable skill is required in fitting them together and producing the ware. When dry, the articles are coated with a slip made of white-burning clays and some flux, and afterwards with a glaze applied in the same way as to terra-cotta. They are then fired in a muffle kiln until the surface becomes glossy. Some firms bake the unglazed ware first, then glaze it and re-fire. Some firms use opaque white glazes.

Like terra-cotta used for architectural purposes, sanitary ware of the kind just described must be accurate in size and shape or it will be useless. Consequently skilled men must be employed in almost every stage of its production, and the greatest possible care is required if satisfactory results are to be obtained.

Drain-Pipes.—The most usual forms of drain-pipes, with their accessories such as traps, gullies, bends, connections, channels, etc., are well known. New patterns are frequently being devised, and for them special advantages are usually claimed.

Drain-pipes should be glazed both inside and out, the most satisfactory glaze being that produced by throwing salt into the kiln just before the burning of the pipes is completed. The salt is decomposed and the soda present in it then attacks the clay forming a complex alumina silicate which melts and produces the glaze. Owing to the manner of its formation, this glaze is more adherent than glazes which have been applied in a completely formed state to the goods.

The best qualities of drain-pipes are made of clays which vitrify when burned, so that they would be impervious to water even if they were not glazed. Some firms, however, make pipes of more heat-resistant clays which are porous. Such clays are satisfactory so long as the glaze covers them completely, but if the glaze is defective the liquids passing through the pipes penetrate into the body and may cause serious trouble.

Pisé-de-Terre.—Pisé-de-terre is dry earth thrown between shuttering, and rammed until consolidated. The shuttering used is 10 ft. long and 2 ft. 9 in. high, 9 in. of which, however, overlaps the completed course, so that 2 ft. is added to the wall at each operation. The same shuttering is then removed from the finished course and raised into position to take the next layer above.

Red marl is the best soil for pisé building, but with the exception of clay, almost any earth would do providing it was free from vegetable matter. Clay is unsuitable owing to its hydroscopic properties; it is really a liquid and impossible to compress. A very neat wall can be built with clay, but when it dries out it is apt to crack. Neither should sand be used, as it has not sufficient cohesion. Deposits of red marl are found in a diagonal band across England from Yorkshire to Devonshire, and is very prevalent in the Midlands.

The next best earth to use is brick earth, or clay that had been well-weathered, broken up, and exposed to the wind and frost. When the earth is rammed the result is the formation of practically an artificial sandstone. It is found that for the best results all the particles in the earth have to be moved laterally as well as downward when ramming, and a rammer which has a wedge-shaped head so that the earth be rammed both downwards and sideways at each stroke is used, and a very close cohesion is thereby obtained.

A combination of corrugated iron, with a sheet of flat iron inside so as to give a smooth wall surface forms an extremely rigid shuttering. The rigidity of the shuttering is very important, as on its ability to withstand pressure depends the hardness with which the earth can be rammed and the uprightness of the wall.

It is not necessary to cover the outside walls, but if this is thought desirable a coat of tar applied hot is the best material. Walls of cottages are built

18 in. thick; but with good soil 12 in. is quite sufficient for a wall one story high, and with improved shuttering this might be even less. Walls on the second stories are built 14 in. thick.

A pliable bitumen damp course should be used. Deep overhanging eaves are advisable to protect pisé walls from the weather.

Asbestos.—Asbestos is now being extensively used in combination with other materials in the preparation of different building materials. The principal sources of supply come from Italy, Canada, South Africa, and Russia. The best quality is the Italian, and the next best the Canadian. Asbestos is a silicate of magnesia, and the Italian asbestos contains nearly 80 per cent. of this substance and only 3 per cent. of iron in combination. The African asbestos contains about 40 per cent. of oxide of iron.

The following table gives an analysis of asbestos from three main sources of supply:—

	Italian Asbestos.	Canadian Asbestos.	South African Asbestos.
Magnesia . .	38	33·0	2
Silica . . .	42	41·0	50
Oxide of Iron .	3	5·75	40

From this it will be seen that the South African asbestos while having the physical properties of asbestos, could be more correctly described as a silicate of iron than a silicate of magnesia.

The Italian asbestos is a variety of hornblende, while the Canadian asbestos is a serpentine known as chrysotile.

On account of its fibrous structure and fireproofing properties, asbestos finds many uses.

Fireproof curtains are largely made for theatres. Asbestos millboard and paper are largely used in building as insulating fireproof materials, and an asbestos paint is used to protect woodwork. In addition, sheets suitable for lining ceilings and walls are now manufactured, either from asbestos with mixtures containing silicate of soda, or from asbestos mixed with Portland cement. An excellent waterproof roofing felt can be made from asbestos and bitumen.

CHAPTER VII

STEEL, LEAD, ZINC, TIN, AND BRASS

THE many varieties of iron used in commerce with their varying properties, including cast-iron, wrought-iron, and all the different kinds of steel, are due to the fact that iron has the property of forming alloys with a great variety of substances of which carbon, sulphur, silicon, nickel, manganese, and tungsten are the most important, and that as a result of the presence of small percentages of these substances its physical properties are profoundly modified.

The primitive methods of manufacturing iron gave a comparatively pure product. A lump of hæmatite, which is an iron ore consisting principally of an oxide of iron, was heated in a charcoal furnace. Owing to the reducing action of the white hot charcoal and the carbon monoxide, the oxygen combined with the iron was removed and a spongy mass of iron left.

The spongy mass of iron when hammered up on the anvil had the properties which we associate with wrought-iron, the nearest approach to pure iron which is commercially obtained.

It could only be fused at a very high temperature beyond the range of ordinary furnaces and therefore was not suitable for making castings, but it was capable of being forged and welded, thus being suitable for the ordinary operations of the blacksmith. Chemically pure iron has only recently been obtained; it is a white metal, resisting attacks by acids which readily attack ordinary iron, and is nearly as soft as lead.

The most important of the alloys which iron forms are its alloys with carbon. When iron is prepared in the modern blast furnaces into which a mixture of coke, limestone, and iron ore is charged and the whole subjected to a powerful hot blast so that a very high temperature is obtained, the iron combines with a considerable percentage of carbon and so forms a fusible alloy which melts and is tapped from the bottom of the furnace.

This crude fusible alloy is known as pig-iron, and on being fused again in a cupola furnace is tapped into moulds thus producing the various cast-iron articles with which we are familiar. Cast-iron is brittle, and cannot be fused or welded. It has neither the toughness nor the tensile strength of wrought-iron.

Steel.—Steel is an intermediate product between wrought-iron and cast-iron. The old method of manufacture was by the cementation process. Bars of wrought-iron were packed in boxes packed with charcoal and subjected for a long time to a red heat.

A certain percentage of the carbon was absorbed by the iron giving rise to a product which could be fused and also could be tempered by sudden cooling so as to become very hard and capable of being ground to a fine edge.

Steel is capable of being modified, from a mild steel which closely approximates to wrought-iron in its properties to a hard tool steel which is brittle but can take a fine cutting edge. The various properties depend on the tempering and on the percentage of carbon present, and also on the percentage of other elements present such as manganese.

Steel was for many ages only manufactured by the process described, and only used for the making of tools and weapons.

By the devising of the Bessemer process and the Siemens Martin process, it was made possible to manufacture steel in large quantities and to put on the market the mild steel which is principally used for constructional work to-day.

Of the various ingredients in steel, the most important is carbon. The mild steel for constructional work contains about 0·3 per cent. of carbon and a certain percentage of manganese which is beneficial.

As has been already stated the various forms of commercial iron contain small quantities of a great variety of substances.

These substances, as the iron cools and solidifies, crystallise from the mass in various complex combinations with each other at different temperatures, the final mother liquor or eutectic alloy solidifying last.

The formation and crystallisation of the bodies depends on the rate of cooling and other conditions, and all the complex phenomena of the tempering of steel, the manufacture of malleable cast-iron and so on, are associated with the formation of these bodies.

It has long been known that on cooling cast-iron slowly, the excess of carbon present crystallised as graphite. Of recent years by the careful polishing, etching, and examining under the microscope of iron and steel, a great deal of most interesting information has been obtained, throwing light on the behaviour and properties of the various complexes we know of under the general name of iron and steel.

The two ingredients which are injurious are sulphur and phosphorus. Sulphur is comparatively easy of removal by oxidising processes, but phosphorus is much more difficult of removal both in the Bessemer and the Siemens Martin open hearth process. As first devised it was therefore necessary to use an ore low in phosphorus. Subsequently, however, the Thomas-Gilchrist process was introduced, by which, by the addition of lime, and the lining of the furnace with dolomite, instead of the silica bricks, it was possible to remove the phosphorus. The new process is known as the basic process and the old process as the acid process, and the steel, as basic and acid steel respectively.

It is usual to allow a slightly higher percentage of phosphorus in acid steel than in basic steel. In constructional steel the phosphorus should be below ·06 per cent. in acid steel, and below ·04 per cent. in basic steel, and the sulphur below ·07 per cent. in acid, and below ·06 per cent. in basic steel, and the manganese should be below ·5 per cent. and silicon below ·04 per cent.

The Testing of Steel.—In the discussion of the properties of stone and concrete, some three methods of testing materials has been described.

1. The crushing test. 2. The tensile test.
3. The bending test.

In the case of steel the most valuable test is the tensile test. The rod or bar is prepared of a certain length and diameter, being turned or planed down in the middle, leaving two thick ends for attachment to the testing machine. The general shape of the specimen being shown in Fig. 20.

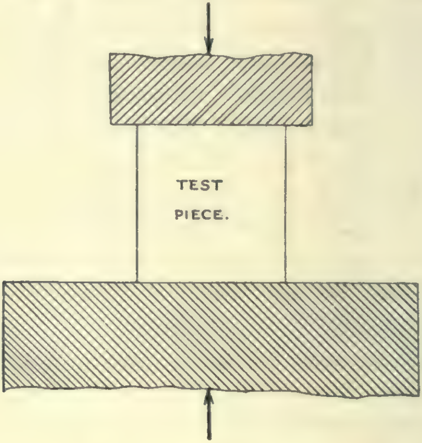


Fig. 16.—Crushing test.

The tension is then applied by the hydraulic machine and the behaviour of the specimen noted.

As the tension increases the specimen is stretched in length, and the amount of this stretching before

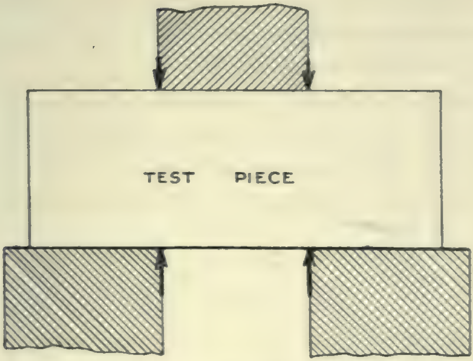


FIG. 17.—Shearing test.

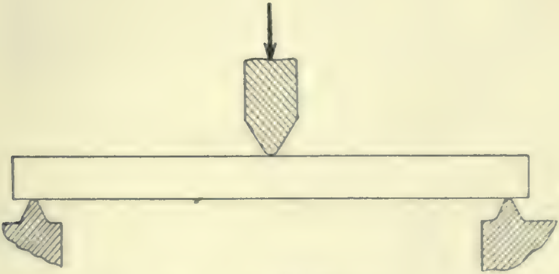


FIG. 18.—Bending test.

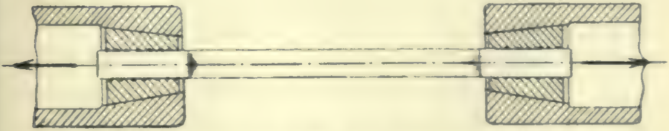


FIG. 19.—Tensile test of Mild Steel, showing method of gripping.

the sample tears asunder must be noted as it measures the ductility of the steel; a very important quality is thus indicated.

As has already been explained, when a substance is stretched or pulled it extends, and if the pull is within the elastic limit of the material, then on releasing the tension the substance resumes its former length.

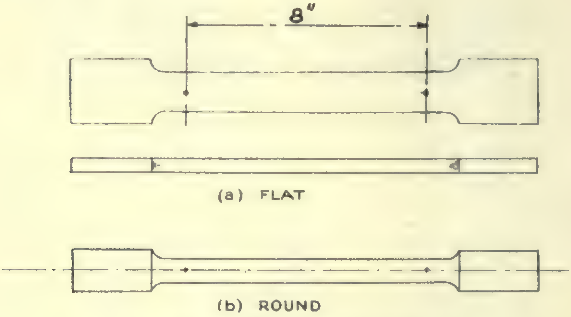


Fig. 20.—Test Bars for tensile tests.

The modulus of elasticity, that is, the actual force applied per unit of area divided by the deformation produced per unit length has also been discussed and defined. The modulus of elasticity of steel may be taken as $E = 30,000,000$ lb. per square inch.

But another very important value is the elastic limit, that is the tension at which the steel no longer recovers its original length on removing the load. In practice it is found that after a certain tension has been reached, the extension of the steel is no longer proportional to the extending force, and this is followed by a tension value where the steel begins to continue stretching a certain amount without any further increase of tension. This is called the yield point and is slightly above the actual elastic limit.

It is evident that this tension, the elastic limit of the material, is the one of practical importance rather than the final tension required to tear the metal asunder, as it is evident that a beam must not be loaded up to permanent deformation although well below its actual breaking load. In commercial testing the yield point is taken as the elastic limit.

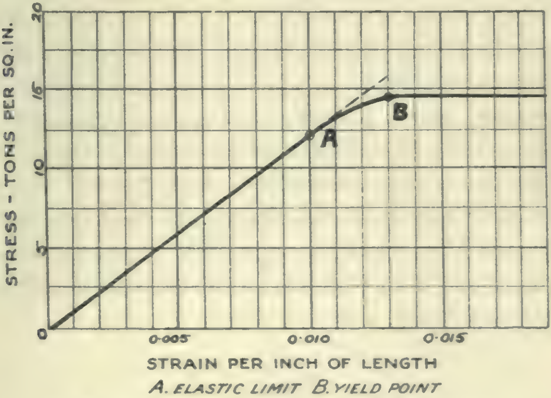


Fig. 21.—Stress-strain Diagram for Mild Steel.

It is usual in American calculations of steel structures to take the elastic limit instead of the final breaking load as the basis for calculation. In the British Standard Specification for testing materials, the following conditions for structural steel are laid down:—

Structural Steel.

Tensile strength in tons per square inch, 28 to 33
Elongation in 8-in. min., per cent.[1]—
  20 per cent. for bars $\frac{3}{8}$-in. thick and over.
  16 per cent. for bars under $\frac{3}{8}$-in. thick.

In calculating steel structures the average value of 30 tons per sq. in. is divided by the factor of safety.

Another very important test of steel is the bending test, the cold steel bar being bent over on itself. The conditions laid down by the American Society of Engineers are that a piece of structural steel bent through 180° round a mandril of the same diameter as the thickness of the bar should not show any fracture.

Lead.

The principal ore from which lead is produced is galena, the sulphide of lead, but it is also obtained from more complex mixtures of sulphides such as the famous Broken Hill ores.

Lead is soft, plastic, and easily fused; it can therefore be melted and cast in moulds, rolled into sheets, or drawn into pipes.

Sheet lead and pipes should be made from virgin soft lead. No re-melted lead should be used. If the sheets are absolutely soft and pliable the lead may be considered good.

---

[1] Round bars 20 per cent. to 24 per cent. according to form of test piece used.

They should also be carefully examined for flaws.

Lead pipes should show a complete absence of flaws and pinholes; if these are made from virgin soft lead they will normally be absent.

The pipes should also be examined to see that the walls are the same thickness throughout.

The tables on this and the following page are useful.

Weight in lb. per superficial foot.	Thickness in inches.	Nearest simple fraction.	Weight in lb. per superficial foot.	Thickness in inches.	Nearest simple fraction.
1	0·017	$\frac{1}{60}$	8	0·135	$\frac{1}{8}$
2	0·034	$\frac{1}{32}$	9	0·152	$\frac{9}{64}$
3	0·051	$\frac{1}{20}$	10	0·169	$\frac{5}{32}$
4	0·068	$\frac{1}{16}$	11	0·186	$\frac{11}{64}$
5	0·085	$\frac{5}{64}$	12	0·203	$\frac{3}{16}$
6	0·101	$\frac{3}{32}$	15	0·255	$\frac{1}{4}$
7	0·118	$\frac{7}{64}$			

Soft water and water containing certain organic acids attack lead and dissolve it. Very serious cases of lead poisoning have thus been caused by the solution of the lead from the lead pipes in drinking water. Fortunately hard waters, which are most usual, rapidly form an incrustation on the lead which prevents further action.

Great care should be taken to test carefully the behaviour of a new water supply on lead, and in case of doubt iron pipes should be used, and especially for hot water, copper tinned internally.

Lead Pipe, Weight per yard (approximate).

	Lb. per yard.
¼ in.	9 oz.
	12
	14
	1 lb.
	1½
	2
	2½
	3
	4
	6
⅜ in.	1
	1¼
	1½
	2
	2½
	3
	4
	5
	6
½ in.	1½
	2
	2½
	3
	3½
	4
	4½
	5
	5½
	6
	6½
	7
	8
	9
⅝ in.	3
	3½
	4
	4½
	5
	5½
	6
	7
	8
	9
¾ in.	3 lb.
	4
	4½
	5
	5½
	6
	6½
	7
	8
	9
	10
	12
	14
⅞ in.	5
	9
	12
1 in.	4
	5
	6
	7
	8
	9
	10
	11
	12
	14
	16
	18
1¼ in.	7
	8
	9
	10
	11
	12
	14
	16
	19
	21
1½ in.	9
	10
	11
	12
	13
	14
	15
	16
	18
	21
1¾ in.	14 lb.
	16
	18
	20
	24
	27
2 in.	16
	18
	20
	22
	24
	26
	28
	30
	35
	40
2¼ in.	15
	20
	25
	30
	35
	40
	45
2½ in.	20
	22
	24
	26
	28
	30
	35
	40
3 in.	25
	30
	35
	40
	45
	50
3½ in.	30
	35
	40
	45
	50
	55
4 in.	35 lb.
	40
	45
	50
	55
	60
4½ in.	40
	45
	50
	60
	70
	80
5 in.	50
	55
	60
	70
	80
6 in.	100
7 in.	120

SOIL PIPE.

IN.	LB.
1	4
1¼	5
1½	6
2	10
2½	12½
3	15
3½	18
4	20
4½	26
5	32
5½	36
6	40

Zinc.

Metallic zinc is obtained principally from zinc sulphide ores.

Zinc is fusible, somewhat brittle, and fairly easily oxidised.

It can be easily melted and cast and becomes malleable at about 220° F., when it can be rolled into sheets which can be used for roofing, gutters, etc.

It is also used for "galvanising" iron to prevent it from rusting.

The following table, issued originally by the Vieille Montagne Company of Belgium, gives the weight per square foot of zinc:—

Gauge.	Approximate Weight per square foot.			Approximate Weight of Sheets, 8 feet by 3 feet.			Average Number of Sheets in a Cask (about) 10 cwts.
No.	Lb.	Oz.	Dms.	Lb.	Oz.	Dms.	
4	0	4	13	7	3	8	153
5	0	5	11	8	8	8	129
6	0	6	11	10	0	8	110
7	0	7	12	11	10	0	95
8	0	8	14	13	5	0	83
9	0	10	5	15	7	8	71
10	0	11	7	17	2	8	64
11	0	13	5	19	15	8	55
12	0	15	2	22	11	0	49
13	1	0	15	25	6	8	43
14	1	2	12	28	2	0	39
15	1	5	12	32	10	0	34
16	1	8	12	37	2	0	30
17	1	11	11	41	8	8	27
18	1	14	11	46	0	8	24
19	2	1	11	50	8	8	22
20	2	4	10	54	15	0	20

Tin and Solder.

Tin is prepared from the oxide of tin known as tinstone.

The metal is soft, malleable, easily melted, and does not readily oxidise in the air.

It is used for making solid drawn pipes which were formerly used for gas fittings in houses but have now been largely replaced by composition pipes.

Solder is an alloy of tin and lead. Ordinary coarse solder is an alloy of 1 of tin to 2 of lead. Fine solder is 1 of tin to 1 of lead.

Brass.

Brass is an alloy of copper and zinc, containing about two parts of copper to one of zinc. It is melted and cast into various forms, and can also be rolled into sheets.

The quality of brass is much affected by the presence of small traces of other metals. A trace of antimony, for instance, is very injurious, while on the other hand 1 to 2 per cent. of lead makes it easier to work, and a small percentage of aluminium adds to its strength and ductility.

Cast brass should have a tensile strength of 40,000 lb. per square inch, and an elongation of nearly 40 per cent. By rolling into sheets the strength is increased and the ductility diminished.

CHAPTER VIII

TIMBER

OF the innumerable trees growing in various parts of the world, only certain kinds are used as timber for constructional purposes, while others again are used for the making of furniture, of tools, and various other manufactures, and others while used locally are not exported. It is only necessary for us to consider here the timber used for constructional purposes in this country.

Such timber is obtained from two main types of trees, the broad leaved trees which, as a rule, shed their leaves every year and are therefore called deciduous trees, and which give us the woods known as hard woods, such as oak, elm, mahogany, and teak, though in addition woods of deciduous trees which cannot be described as hard, such as poplar.

The other great family of timber supplying trees are the needle leaved conifers, which do not as a rule shed their leaves, and to which belong the pine, fir, spruce, larch, hemlock, and cedar trees.

Both these great families of trees have a common method of growth in thickness or girth, which distinguishes them from the great family of endogenous trees to which the palms belong.

The exogenous trees which we have just been considering, increase in girth in the following manner.

Starting from the central pith, a fresh layer of wood is formed each year surrounding that of the previous year and lying underneath the bark, and so year by year a fresh ring is added to those already formed.

As this process continues the inner or older rings cease to constitute part of the living portion of the wood body of the tree becoming a central column of support, and acting as a storehouse for water. Surrounding this central heart-wood, which is sometimes darker in colour, is a zone of wood consisting of a varying number of year rings, usually lighter in colour than the heart-wood, and is called the sap-wood. This sap-wood is still alive and takes part in conducting water from the roots to the leaves.

Between the outermost year ring and the bark is a ring of actively growing tissue called the cambium.

Owing to the difference between spring and summer growth of the annual rings, there is a difference in colour and texture which makes each year's growth distinct from the next.

If a cross-section through a coniferous tree is examined under a lens the actual structure is made visible, the wood being built up of tiny narrow vertical cells (the tracheids). Running through and among these closed cells are the resin ducts which are continuous tubes.

In addition, there are groups of cells running radially from the centre towards the circumference known as the medullary rays.

This cellular structure governs the conditions during the seasoning and drying of timber.

The cell-walls are loaded with water and during drying lose this water and shrink in cross-section but alter very slightly in length, so that the timber in drying shrinks radially, and also in the direction at right angles to the radius or tangentially, but not so much longitudinally. This radial and tangential shrinking results in "warping" and "checking," thus making the seasoning and drying of wood a difficult operation.

The structure of conifers is comparatively simple, consisting of long straight cells, with occasional resin ducts. Consequently the timber is easily split and worked.

The cell structure of the hard woods is much more complex, making them tougher, harder, stronger, and more difficult to work.

At the end of the chapter a brief list will be found of the principal trees used for constructional timber, with a statement of the sources of supply, and of the varying names under which the timber from the same tree is known in the trade, which as far as possible has been made up to date.

Seasoning or Drying of Timber.—Before being used, wood requires to be dried, that is to lose a certain percentage of its contained water. This water is present, partly within the wood cell, and partly in the cell walls themselves, and partly combined with the protoplasm and other cell contents of the living elements of the wood.

It is therefore impossible to dry timber com-

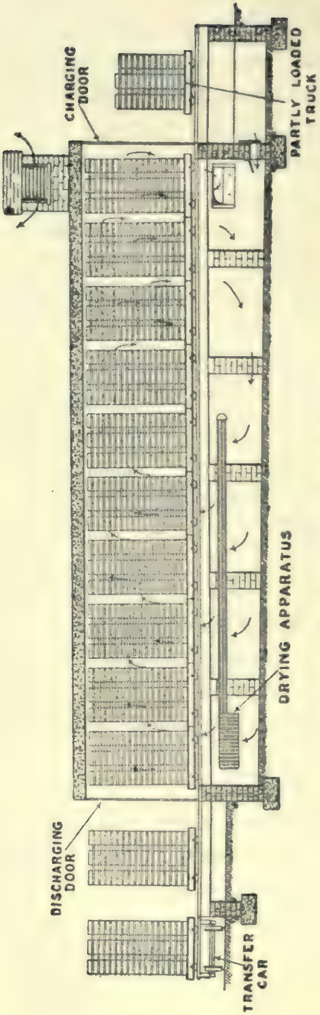

CHARGING DOOR
PARTLY LOADED TRUCK
DRYING APPARATUS
DISCHARGING DOOR
TRANSFER CAR

Fig. 22.—Drying Apparatus.

pletely. The wood continues to lose water as the temperature rises, until the temperature is reached at which the wood itself begins to decompose.

Moreover, on again exposing to air at ordinary temperature, it again absorbs water.

The process of drying, therefore, requires to be carried on only to a certain extent, and great care must be taken to avoid undue warping or checking in the process.

Nearly all timber is air-dried, but kiln drying is more and more coming into vogue to save time. For kiln drying, temperatures of about 120° F. are usually employed, and pine, spruce, cypress, and cedar can be dried fresh from the saw. Hard woods should be air-dried first for from three to six months, and lower temperatures employed and a little steam introduced to prevent checking and case hardening.

The rapid seasoning of timber has been recently perfected by a process known as the Erith system.

In the Erith system the timber is moved through the kiln occupying ten days in transit. It is first subjected to a comparatively low temperature, which increases within the kiln to 120° F. At the same time a certain degree of moisture is introduced and a complete circulation of the warm moist air caused; while the process is controlled by readings on wet and dry bulb thermometers, the reading on the wet bulb thermometer being kept at 110° F. while the dry bulb stands at 120° F.

An account of the system by Sir Frank Baines, as the result of the experience of the Office of Works who used the system to season timber during the war, will be found in the *Timber Trade Journal* for the 7th June 1919.

While at the present time the user of timber prefers heart-wood to sap-wood, as the sap-wood is inferior in strength and more likely to decay, the rapid exhaustion of the forest reserves of the world will compel him to use rapidly growing timber like Loblolly pine which consists largely of sap-wood. It is, moreover, probable that many of the defects of sap-wood can be overcome by scientific methods of drying and seasoning. There are also possible sources of supply from tropical countries of material to replace timber such as the bamboo.

The Mechanical Properties of Wood.—The experienced buyer of timber examines it for certain qualities before purchasing.

The wood should be free from large knots and from "shakes," and the surface should not be woolly but should have a fine bright silky lustre when planed.

It should be straight in fibre and the annual rings regular in form.

There should be no indication of decay from attack by fungi.

The timber should be as free from sap-wood as possible.

It has not been customary here for house constructional purposes to apply more rigid tests, such as those usually employed for such materials as steel, but it has been customary, on the other hand, to allow an ample margin of safety in the constructional design where timber is used.

Owing to the increasing price of timber it is no longer possible to use it so freely as in the past, and it therefore becomes important to apply to it the rigid tests which are required for steel and to design accordingly.

Unfortunately it is not possible in the case of timber to obtain such uniform results as are possible in a uniform material like steel.

If a particular tree is selected for experiment, let us say *Pinus sylvestris* (the Scots pine), it will be found to give varying values under tensile, compression, shearing, and bending tests, according to the source of supply, the portion of the trunk selected, the seasoning, the straightness of fibre, the presence or absence of knots, and so on.

Consequently all published figures for a particular kind of timber must be regarded as approximate if used as a basis for calculation in constructional work.

The values most commonly required in calculating the amount of timber needed for structural purposes are the modulus of elasticity and the modulus of rupture, for timber used as a beam.

If we suppose a beam of known length and section supported at the two ends and loaded in the middle, the beam will bend under the load, and if the load is not too great will recover. If the load is steadily increased the beam will bend further and further, and at last a load will be reached at which on removing the load the beam will no longer recover, "the elastic limit" has been attained, and on slightly increasing the load beyond this point the beam will break.

In designing a beam it is necessary that it shall be sufficiently strong to carry the load and sufficiently stiff not to yield perceptibly under the load.

We require, therefore, to know both the modulus of elasticity, that is the amount of yield for a given load, and the modulus of rupture, that is the resistance offered by the extreme fibres at the breaking load.

These values can be obtained experimentally by taking a piece of timber of known cross section and known length between the supports, loading it in the middle, measuring the deflection for different loads and the final load required to break the beam.

Then if W is the load in lb., l the length of the beam, b the breadth, and h the depth, and d the deflection in inches,

$$\text{the modulus of elasticity } E = \frac{Wl^3}{4dbh^3},$$

$$\text{while the modulus of rupture is } F = \frac{3Wl}{2bh^2}.$$

It is evident, therefore, that these values having been experimentally determined, we can make the necessary calculations for any given beam.

The following values are taken from the *Principal Species of Wood*, by Snow :—

Name of Timber.	Modulus of Elasticity.	Modulus of Rupture.
English Oak . .	1,170,000	10,000 (Thurston).
Teak . . .	1,338,000 2,100,000	15,000 (Thurston).
Scotch Fir . . (*Pinus sylvestris*)	1,800,000	7,000 (Thurston).

These figures for the modulus of rupture are all probably much too high and should be divided by two before being used in any calculations. In all cases a factor of safety of ten should in addition be allowed.

Tests of timber for tensile strength and strength under compression are made in the same way as for other material.

The tensile strength of a stick a square inch in section varies from 17,000 lb. to 32,000 lb. for different kinds of timber, and the crushing strength of timber varies per square inch from 8500 to 7400 lb.

A very important measurement to make is the shearing strength of wood along the grain.

In the case of a mortice and tenon joint, the tenon of the beam which is carrying load, is applying a shear on the lower portion of the mortice of the morticed timber. Johnson gives the resistance to shear along the fibre as 1000 lb. per square inch for oak and 400 lb. per square inch for pine, spruce, and cedars.

It is evident that the resistance to shear of timber is low, and that this fact should not be left out of account in calculating the dimensions of morticed timber.

In the foregoing pages the testing of wood for crushing, bending, and shearing strength has been described. It remains to give some account of the important conclusions arrived at by the Forestry Department of the United States as the results of their many experiments.

In the first place it is found that the density of the wood increases as it passes from the green to the dry condition. At the beginning of the drying no increase of strength is observed. This is the stage at which the cells are losing their contained water.

When this stage is passed and the cell walls begin to lose their absorbed water and shrink, their strength increases with the dryness of the wood when tested in small perfect specimens, as for instance beams 2 in. × 2 in. × 30 in. long.

It might therefore be argued that all tests should be made on dry properly seasoned timber.

Experience, however, with larger timbers does not confirm this conclusion.

In larger timbers owing to the internal stress set up, the drying process results in checking, splitting of cell walls and so on, so that the weakening by these changes may easily counteract the increase of strength from drying.

To take an example from the tables in *Mechanical Properties of Wood* from records compiled from the U.S.A. Forestry results, a piece of long leaf pine 2 in. × 2 in. × 30 in. had a modulus of rupture of 9070 when green and of 11,520 when air seasoned.

On the other hand, beams of long leaf pine of 12 in. × 12 in., 6 in. × 16 in., and 6 in. × 8 in. section, and from 138 in. to 180 in. long gave very different results.

When green, the following figures for the modulus of rupture were obtained:—6710, 6453, 5439, 6460, 6500, and 5745. While for the seasoned timber the figures are 4274, 6610, 7880, 8000, and 8196.

It will be noted on examining the figures, that in the first place these are all much lower than those obtained from testing small beams; in the second place the figures for the seasoned beam is in one case actually lower than any figure obtained for the green wood, and in the third place the figures for seasoned wood vary much more among themselves than the figures for green wood.

In order, therefore, to obtain reliable figures for calculations for structural purposes, the green timber should be tested in large beams.

The early experiments on timber were all made on small carefully seasoned pieces. When these are the only figures available, they should be divided by two before being used as a basis of calculation.

The tables quoted above show that for large timbers of green wood, the modulus of rupture for long leaf pine varies from 5430 to 6710.

Douglas fir varies from 4699 to 5983, Western larch from 4636 to 5331, Red wood from 3753 to 5279, Norway pine from 3572 to 4205.

In the case of figures taken from older books care should be taken to note whether they are for small or large pieces of timber, and they should be used with caution in calculations.

For instance, it will be noted from the results given for long leaf pine, it is quite possible that a beam might have a modulus of rupture of only 4724, while the experiments on small beams give a result 11,520, thus justifying the advice to divide by two, values given by older observers before proceeding to allow for the required factor of safety.

It will also be noted that all the values already quoted from Thurston are much higher than those by later observers.

Before leaving this subject it is necessary to point out the weakness caused in a beam by knots which are due to the outgrowth of a limb from the parent stem.

The presence of a knot has a weakening effect on a beam. If the knot is on the upper side of the beam, and therefore in compression, its presence does not matter. But if it is on the lower side of the beam, that is in tension, the beam is weakened, and as the strength of the beam varies as the square of the depth of the beam, a knot may become a very serious source of weakness.

It is to be regretted that we have not got in this country as they have in America, a Government Department to publish from time to time up-to-date tests of European timber.

Density.—The density of wood is defined as the weight per unit volume, usually stated in lbs. per cubic foot, and the wood is supposed to be air-dried. In laboratory measurements of density the wood is dried at 100° C.

The crushing strength, bending strength, and shearing strength along the grain increase with increase of density.

Dry Rot.—Timber is apt to be attacked in presence of moisture by wood-destroying fungi, of which the two best known are *Polyporus vaporarius* and *Merulius lacrymans.*

Polyporus vaporarius most frequently attacks timber in the early stages after felling and before passing through the saw-mills, producing the appearance in the wood known as "red stripe." If timber affected with the spores of "red stripe" is used in building and has not been sufficiently dried in seasoning to kill the spores, under favourable circumstances, owing to the presence of moisture, the spores will grow freely on the timber and destroying it, producing effects similar in appearance to the attack of *Merulius lacrymans.*

Merulius lacrymans is seldom found in forests, being usually found in connection with inhabited places, the infection of new timber taking place from old timber lying about wood-yards, or even from the tools and clothes of carpenters who have been pulling down old timber in which dry rot is present.

The spores can only germinate and flourish in presence of moisture and some free alkali such as ammonia, which may be due to soil, coal-dust, or other organic impurities.

In the first instance the wood is attacked, the fungus afterwards growing outside the wood and spreading over every neighbouring surface such as the inside of walls, and attacking any fresh timber it meets with. The fresh timber attacked may be quite dry, the necessary moisture being supplied by the fungus, drawn from its original starting point.

Care should be taken that all timber is dry and well ventilated and nowhere in contact with humus; sometimes the deadening material put between floors is both damp and alkaline, thus starting the trouble.

All portions of timber likely to become damp in contact with outer brick walls and so on, should be saturated with tar oils such as creosote which are both antiseptic and waterproofing.

Too early tarring or painting of wood is often a cause of trouble, the moisture in the imperfectly dried wood being prevented from evaporating, and so producing conditions favourable to attack by the fungus.

If the dry rot fungus is present, the most drastic treatment and removal of all doubtful timber is necessary, with a thorough removal of the source from which it has originally grown and obtained its supply of water, and introduction of ventilation and creosoting of all possible sources of further trouble.

Impregnation of Timber.—Many substances have been tried for the impregnation of timber to prevent decay.

The impregnation with zinc chloride (Burnett process) and impregnating with creosote are those most commonly used, and of these, impregnation with creosote is the best.

The amount of creosote the timber can take up depends on the nature of the wood.

For Baltic and pitch-pine timber J. R. Baterden (*Timber*, Constable) lays down the following specification:—

"All timber which receives less than 7 lb. of oil per cubic foot at the first tanking will be retanked; all timber which receives less than 6 lb. of oil per cubic foot at the second tanking will be retanked; and all timber which receives less than 5 lb. per cubic foot is liable to rejection."

The creosote oil when tested at 60° F. should have a specific gravity not less than 1·045, and should contain not less than 10 per cent. of crude carbolic and other tar acids.

Fire-proofing. — Many substances have been proposed for fire-proofing timber. Of these probably the best are preparations containing phosphoric or boracic acid; of these ammonium phosphate is an excellent fire-proofing agent. Ammonium chloride, ammonium sulphate, calcium chloride all also act as fire-proofing agents.

The following is a brief account of the principal trees used for constructional work in this country.

Conifers.

The conifers arranged under their proper designations described below are confined to those used or largely imported for constructional purposes.

The Pines (*Pinus*).

The Northern pine or Scots pine (*Pinus sylvestris*).—Grown for timber in this country and imported from Russia, Prussia, Norway, and Sweden. Also known as Dantzig, Riga, Memel, Stettin, and Swedish fir. The timber known as Red wood, Yellow wood, and deal. Strong and durable.

Yellow pine (*Pinus strobus*).—Exported from Canada; also at one time plentiful in North-Eastern and North Central United States. Also known as White pine, Weymouth pine, Soft pine, Northern pine, and Spruce pine. Light in colour, clean and free from knots, easily worked and soft.

Red pine (*Pinus resinosa*).—Grown in Southern Canada and Northern United States, and Nova Scotia. Also known as Norway pine, Hard pine, Canadian Red pine in America, and in Nova Scotia as Yellow pine.

Pitch pine (*Pinus palustris*).—Grows on the South Atlantic coast and Gulf States. Also known in America as Long Leaf pine, Georgian pine, Yellow Georgian pine. Very hard, heavy, tough, and resinous. Consequently very durable but difficult to work. Used for heavy timber work. The "Pitch pine" of America is *Pinus rigida.*

Loblolly pine (*Pinus tæda*).—This tree grows in the Southern States of America from Virginia to Texas. The timber is coarser, softer, and more full of sap than Long Leaf pine. It absorbs creosote freely owing to the amount of sap it contains, and requires immediate kiln drying if going to be used for internal work to prevent fungus attack. It grows very rapidly as compared with other pines such as Long Leaf pine. It is equal to Long Leaf pine in bending, compression across the grain, and shearing tests. The main objection to it is the great quantity of sap it contains.

J. R. Baterden on *Timber* says of the Southern pines: All the Southern pines go by the name of "Yellow pine" in the American markets. Long Leaf is considered best, then follow in order of importance Short Leaf, Loblolly, Cuban, and *Pinus rigida.* The "Pitch pine" (*Pinus palustris*) of the English market is considered the best, but there is little doubt that many of the others are imported under the name of "Pitch pine."

Spruce (*Picea*).

White deal (*Picea excelsa*).—Imported from the Baltic. Not so strong and durable as *Pinus* *sylvestris.* Also known as Norway spruce and White fir. The timber known as White deal.

Black spruce (*Picea nigra*).—Grown in Canada and also in the United States, in Pennsylvania, Minnesota, and North Carolina.

White spruce (*Picea alba*).—Grows in Canada and Northern United States.

Hemlock spruce (*Tanga albertiana*).—Grown on the Pacific Coast in northern regions.

Oregon Pine (*Pseudo-tsuga*).

Formerly regarded as fir, now classified as a bastard Hemlock. Grows on Pacific Coast from Mexico to British Columbia.

Also known as Douglas fir, Red fir, Yellow fir, Red pine, and Puget Sound pine.

Larch (*Larix*).

Grows freely in Great Britain and Northern Europe (*Larix europea*); also in United States and Canada where it is known as Tamarack or American larch (*Larix americana*). Very tough and durable.

Red Wood (*Sequoia*).

Grows in California. Two species known, *Sequoia sempervirens*, supplying the common Red wood, and *Gigantea.* The wood is soft, light, clean, reddish brown, and very durable.

Cypress.

Several species of the true cypress (*Cupressus*) are known in America. In addition the American "swamp" cypress is a Taxodium and grows in the

Southern States of America. The wood is clean and durable.

Kauri Pine (*Dammara Australis*).

Grows in New Zealand. The wood is fine, smooth, silky, and fairly durable.

Deciduous Trees.

Oak (*Quercus*).

Two varieties of oak are native to England, *Quercus pedunculata* (the English oak) and *Quercus sessiliflora* (the Scottish oak).

These oaks are also common throughout Northern Europe. The timber of these oaks is straight grained, elastic, and durable. It takes a long time to season thoroughly and warps a good deal in seasoning. Owing to the presence of gallic acid in the wood, galvanised iron bolts should be used in preference to iron bolts, as iron is apt to be corroded. Dantzic, Stettin, and Riga oak come from the same trees and are superior to American oak.

In addition to these two varieties *Quercus ilex* and *Quercus ceris* are European and supply timber. In the United States and Canada there are a large number of different species, the one usually exported being the White oak (*Quercus alba*). Live oak (*Quercus virens*) is no longer exported.

Several varieties of oak are also found in Japan, the principal varieties being Shira Gashi (*Quercus glauca*), Aka Gashi (*Quercus aeuta*), and Onara (*Quercus crispula*).

Mahogany.

Mahogany is found in West Africa, Central America, and the West Indies, the main source of supply being the West Coast of Africa. It is close and straight in grain, and is not subject to warping and is very durable.

Teak (*Tectona grandis*).

This tree grows in various parts of India, and is also found in Java and Cochin China. The principal supplies are obtained from Burmah and Siam. Teak does not crack or shrink after being cut, is hard and straight in grain, is stronger and stiffer than English oak, and is very durable and does not corrode iron.

In addition to the timber above described, and which is used for constructional work in this country, there are innumerable other trees used for timber for other purposes, and in addition many trees which are used for constructional work locally, but not imported by this country.

To mention some of the commoner kinds we have in Europe, the Yew, the Hornbeam, the Sycamore, the Plane, the Sweet Chestnut, the Horse Chestnut, the Willow, the Lime, the Common Cypress, the Ash, the Birch, the Beech, the Elm, and the Poplar. A list of timber grown in the British Empire can be obtained from the Board of Trade. A company has recently been started to build houses entirely of English Elm.

CHAPTER IX

PAINTS AND VARNISHES—WALL PAPER—STOCKHOLM TAR, COAL-TAR PITCH—CREOSOTE OIL—KNOTTING—PASTE—WILLESDEN FABRICS—GLUE—SIZE —PUTTY—ASPHALT

AMONG the many pigments which are known only a certain selection are of interest to the builder, while others are used by the lithographer, the painter of pictures, and so on.

The following is a brief description of the more important pigments of use in building operations.

Whites.—White lead is a complex of carbonate and hydrate of lead, that is a basic carbonate of lead, in which the proportion of hydrate to carbonate varies within certain limits.

The old process known as the stack process still produces the best quality of white lead.

In this process, the metallic lead is cast into grids which are placed over small earthenware pots containing dilute acetic acid, and packed round and over with spent tan.

The acetic acid vapours start the corrosion of the lead, while the slow fermentation of the spent tan supplies the carbonic acid. After some weeks the stacks are pulled down and the lead grids, largely converted into basic carbonate of lead removed, and the basic carbonate separated from the unacted in lead, and washed and dried.

The following analyses of good English stack lead are taken from Hurst's *Painters' Colours, Oils, and Varnishes*:—

Lead monoxide . .	86·35	85·93
Carbonic acid . . .	10·44	11·89
Water	2·95	2·01

These may be taken as typical examples of high quality white lead. White lead is frequently sold ground into a stiff paste with linseed oil. The following two analyses taken from Hurst are typical of a good quality product:—

Lead hydroxide . .	65·96	71·14
Lead carbonate . .	25·19	20·45
Oil	8·34	8·34

White lead remains the favourite white with house painters because of its good covering qualities and easy working under the brush. The objections to it are:—

1. That it is very poisonous.
2. That it darkens in impure air containing sulphuretted hydrogen.

It has been long regarded by house painters as the most durable pigment for outside work. Exhaustive experiments in America have shown that pure white lead alone is not so durable as certain mixtures to be discussed later.

Zinc oxide is prepared by distilling zinc and burning the zinc vapour. The white oxide thus obtained is then roasted before being put on the market. Zinc oxide requires a larger percentage of oil than white lead.

Weight for weight zinc oxide has the same covering power as white lead, but it takes some five coats to cover as well as three coats of white lead. It is non-poisonous and unaffected by impure gases. It is now largely used in the preparation of white enamels.

High grade zinc oxide should not contain more than ·2 per cent. of lead.

Lead Sulphate, Zinc Oxide Whites.—A series of whites can be obtained by subliming and roasting lead and zinc ores at a high temperature.

These range from pure lead sulphate obtained by roasting galena or lead sulphide to zinc oxide.

They are extensively used in America and are excellent pigments, being intermediate in covering power between white lead and zinc oxide.

Lithopone or Charlton White.—This pigment was originally invented by Mr Orr for use in linoleum manufacture. It is prepared by mixing a solution of zinc sulphate with a solution of barium sulphide. The result is a double decomposition and precipitation of a mixture of barium sulphate and zinc sulphide. This precipitate is then roasted. It is an excellent pigment having about the same covering power as white lead, non-poisonous, and unaffected by impure gases.

It is largely used to-day for undercoatings and washable distempers. It has one unfortunate peculiarity, when exposed to sunlight it darkens in colour, recovering again in the dark. Ultimately the pigment recovers and retains its white colour.

Extenders.—There are certain substances which should be regarded rather as extenders than as white pigments, as they have little covering power in oil. While sometimes used for gross adulteration, their presence does not necessarily mean adulteration.

The introduction of such extenders into white paint for instance, up to about 10 per cent., improves its durability for outside work. Furthermore, there are some pigments such as chrome green, which are of such staining power that they would be very expensive to use pure. While, therefore, the use of extenders cannot be objected to, a statement of the percentage present should be insisted upon in all specifications. The most important extenders are barytes (the native mineral sulphate of barium), and finely divided silica and asbestine.

Whitening.—For use in distemper the commonest and cheapest material is whitening or Spanish white. This is simply chalk (calcium carbonate) which has been prepared by grinding and floating. This method of preparation which is applied to many mineral pigments is carried out as follows:—

The pigment is ground in suitable mills with water and then run into a series of settling tanks. The coarser particles are allowed to settle in the first tank and the water and suspended matter allowed to flow into another tank in the series, and so on. The final tank gives the finest product.

Titanium oxide has recently been introduced as a white pigment. It seems to have excellent properties.

Red Pigments.

Oxide of Iron.—The commonest red pigments used in the building trade are those depending for their colour on oxide of iron. These red oxides may be native or artificial.

Large quantities of a Spanish hæmatite, for instance, are used as a brownish-red paint more especially for painting iron. There are also red ochres in the market obtained by roasting yellow ochre. There are also oxides of iron produced by roasting sulphate of iron and other waste liquors obtained from pickling works and so on. All these red oxides from whatever source are absolutely permanent.

Red Lead.—This is an oxide of lead produced by roasting litharge, a lower oxide, at a low red heat. Like all lead pigments it is liable to change in impure air. It is used as an undercoating and also as a preservative paint for iron and steel.

Vermilion.—Vermilion is the red sulphide of mercury.

Absolutely permanent for indoor decoration, it turns brown when exposed to sunlight and should not therefore be used for external decoration.

Scarlet Cadmium.—This is a comparatively new cadmium sulphide. It is absolutely permanent, and worthy of the attention of architects for high-class decorative work.

Red derived from Coal-tar Derivatives.—Of these the only ones of sufficient permanence to deserve notice are:—

1. The alizarine reds obtained from the drying

principle of the madder root which is now prepared synthetically. 2. The diazo reds. This group of brilliant scarlet pigments are the most permanent of all coal-tar colours.

Orange and Yellow Pigments.

Yellow Ochres and Raw Sienna.—The ochres are natural earths which owe their colour to hydrates of iron. They are absolutely permanent.

Raw sienna also contains manganese as well as iron. It is also a permanent pigment. They are all prepared for the market by grinding and floating.

Chrome Yellow and Chrome Orange.—These pigments are compounds of chromic acid with lead. They have therefore the defects of all lead pigments, being discoloured by impure air, but under proper conditions they are very permanent samples of chrome yellow eighty years old on pictures being quite fresh and pure.

They are usually let down by the inclusion of sulphate of lead, calcium sulphate, barytes, etc.

A genuine chrome yellow should contain nothing but chromate and sulphate of lead.

Zinc Chrome.—Zinc chromate is a fine yellow and useful pigment. Very fairly stable.

Greens.

Brunswick or Chrome Green.—These are mixtures of chrome yellow, Prussian blue, and barytes.

A certain addition of barytes is justifiable, but this pigment should not contain less than 40 per cent. of chrome yellow and Prussian blue. An analysis along with a price should be insisted on as adulteration has been known up to 95 per cent.

If an analysis cannot be obtained, the best can easily be selected by grinding weighed samples with a weighed quantity of white lead or zinc oxide in oil with a muller and choosing the strongest tinter. These greens are fairly permanent inside but soon change outside.

They are at once destroyed by lime.

Guignet's Green, Viridian, Chrome Green.—This pigment is unfortunately sometimes called chrome green, thus confusing it with the greens just described.

It is a very beautiful and absolutely permanent green, and is a sufficiently strong stainer to admit of some reduction with barytes. It should always be used for important external work.

Blue.

Prussian Blue.—This blue is prepared by precipitating ferrous sulphate with potassium ferrocyanide and oxidising the product.

It is a pure greenish-blue and a strong stainer. It is sufficiently permanent for inside work, but not for use outside. It is at once destroyed by lime and therefore cannot be used for distempers.

Lime Blue.

Ultramarine.—This blue is prepared by heating together soda, alumina, carbon, and sulphur under proper conditions. It is a powerful purplish blue and is permanent; it can be used for distempers as it is not affected by lime, but is very sensitive to acid.

Brown.

Umber.—Raw umber is a brown earth which owes its colour to the presence of manganese.

Burnt umber is prepared by roasting raw umber. They are both absolutely permanent.

Vandyke Brown.—Several different pigments are sold under this name, from bituminous earths to charred organic matter; they are fairly permanent.

Black.

Lamp Black.—This black is obtained by allowing oily matter to burn without sufficient air and collecting the soot. It is quite permanent.

Carbon Black.—This is a fine, strong, rich black, prepared from natural gas in America by burning with insufficient air. It is quite permanent.

Bone Black.—This is prepared by charring bones in closed retorts. It is quite permanent.

Graphite.—This black is prepared from natural or artificial graphite. It is largely used as a protective paint for iron, and is quite unchangeable.

Oils and Varnishes.

Linseed Oil.—The principal oil used for paints is linseed oil, which is expressed from flax seed. This oil is what is known as a "drying" oil, because on exposure of a thin film to air it oxidises into a tough leathery film. This change is really due to the oxidation of the linseed oil by the air. It is this property which makes it of value as an oil for paint. A good sample should have the following properties:—

Sp. gr. at 15° C.	·933
Iodine value	180
Saponification No.	191
Free fatty acids	3·2
Unsaponifiable	1·4
Moisture	·2

Boiled Oil.—This is linseed oil which has been boiled with certain agents, such as litharge, manganese borate, or oleate, or linoleate, or cobalt resinate, which act as "driers," that is, hasten its tendency to oxidisation.

If zinc white is going to be used in a situation where it may be exposed to the action of impure gases, care should be taken not to use an oil which has been prepared with a drier containing lead compounds.

Tung Oil or Chinese Wood Oil (*Aleuritis cordata*).—Many other drying oils have been of late years introduced into the market.

The most important is Chinese wood oil, which has been used as a drying oil in China for many centuries. This oil will be found very suitable for grinding with pigments which are to be laid directly on cement. It should be used in place of linseed oil for this purpose. On account of its property of drying flat, it is being used for the preparation of "flatting paints," which are quite different in their properties from the old flatting paints produced by adding turps, wax, and borax. A new type of varnish is also being prepared from this oil.

Drying oils are now being prepared from Soya bean, sunflower seed, and other sources.

Volatile Mediums.

Spirit of Turpentine.—The best turpentine is prepared by the distillation of the pine balsam of certain American pines (*Pinus australis* and *Pinus tæda*). The turpentine distilled from the wood or sawdust is not considered to be of the same quality. Other turpentines such as French turpentine and Russian turpentine are also used. Turpentine is useful as a thinner as it mixes with oil, evaporates readily, acts as a drier promoting oxidisation of the oil.

If too old it may have become resinous, in which case it is apt to cause cracking. A good quality of turpentine should have a specific gravity of ·862 to ·875, a boiling point of about 150° C., while 95 per cent. should distil between 153° to 165°, and not more than 5 per cent. should be unpolymerised after half an hour. It should leave no grease spot and be free from water. (Gardner's *Organic Analysis.*)

Petroleum.

Various light petroleum oils and mineral naphthas are in the market as thinners and usually sold as white spirits. They are all excellent if properly rectified. Benzole is also used, which must not be confused with benzine which is one of the petroleum preparations.

If a few drops are placed on blotting paper, the petroleum should evaporate without leaving a greasy stain.

Resins and Varnishes.

The most common resins are copals from Africa, the hard copals forming the hardest varnishes known, kauri gum from New Zealand, dammar, mastic, rosin, and shellac.

There are two types of varnishes, spirit varnish and oil varnish. The spirit varnishes are resins dissolved in spirits of turpentine or alcohol. Methylated spirit is denatured alcohol. When these varnishes are painted out the volatile solvent evaporates leaving a layer of pure resin behind. For making these, resins, such as dammar, mastic, rosin or shellac, are used. They are all comparatively friable, the best and toughest being shellac varnish obtained by dissolving shellac in alcohol.

Oil Varnishes.

These are prepared by fusing the resin and mixing it with linseed oil and a suitable "drier," and heating until a drop taken out cools clear, thinning with turpentine, and allowing to settle and mature. These are the only varnishes suitable for permanent and outside work. The hardest and best are made from hard copals and are used for railway carriages. In addition to these there are new products coming into the market.

These are resin esters prepared from other resins which are harder than resins themselves, and synthetic resins prepared from phenol, which are very hard and durable, and from which certain varnishes can be made.

Varnishes prepared from Chinese wood oil are also coming into use. Common resin which, when dissolved in linseed oil gives a soft and sticky varnish, makes an excellent varnish when dissolved in tung oil, under suitable conditions. Still better varnishes are obtained by dissolving resin esters in tung oil.

Enamels.

Enamels are prepared by grinding a suitable white zinc oxide, either in a specially thickened oil prepared in Holland known as standt oil, or in an oil varnish with some addition of a volatile diluent.

In specifying an enamel, the maker should be required to state the ratio between resin, oil, and diluent, as the durability and absence from cracking depends on having a proper proportion of oil present.

Size, Casein, and Washable Distempers.

Ordinary whitewash is made up with chalk and size (size being a weak glue prepared from hides).

Various recipes are given for washable distempers, the principle on which they are made up in most cases being to prepare an emulsion of size and drying oil, or still better of casein and oil.

Casein which is the nitrogenous residue in cheese, if treated with lime, soda, or ammonia, becomes soluble, and in drying forms a strong binder. The binding properties are still further improved by treating with formalin. Casein alone, or emulsified with oil, makes an excellent medium for a washable distemper. Usually lime is added in sufficient quantities to get the casein into solution.

Washable distempers should be tested by painting out on a suitable plaster surface, and seeing how well they adhere both when treated to dry rubbing and to sponging, and by painting out on paper and when dry folding sharply to see whether they crack along the folded edge and flake off.

In order to find out if the pigments are affected by lime, paint out the distemper on a piece of paper. Make up a wet paste of lime, press the under surface of the paper down upon it so that it is wetted through, and leave it in contact for twenty-four hours. Green distempers are the most likely to prove fugitive. They should also be tested for covering power, putting a weighed quantity on a given area and noting weight and number of coats.

Driers.

Reference has been made more than once to "driers." These are substances which hasten the oxidation of "drying" oils like linseed oil. The oldest and best known driers are litharge and sugar of lead, but both manganese and cobalt compounds such as manganese borate, resinate and linoleate, and cobalt resinate are powerful driers. Liquid driers are solutions of such of these compounds as can be dissolved in organic liquids, and paste driers are these materials mixed with an unknown quantity of barytes, or some similar inert material.

Ready Mixed Paints.

In the foregoing pages a brief description has been given of the commoner raw materials used in the preparation of paints, enamels, and varnishes. It is becoming more and more customary to buy the pigments already ground in oil. White lead, for instance, is usually sold as a stiff paste in oil, which requires to be broken down with more oil, driers, and turpentine. And, furthermore, ready mixed paints prepared for use without further treatment are coming more and more into use.

As will have been seen in the former pages, fresh materials are also coming into prominence such as tung oil, which are modifying all our preconceived ideas. As a result of these many changes, the question of paint specifications, always a difficult one, is becoming more difficult. A paint requires to have elasticity, body, spreading capacity, durability, and impermeability.

Elasticity can be tested by painting out films and testing their behaviour under tension.

Many such experiments have been made here and in America. Body is usually tested by finding the weight of pigment required when laid on as a paint to obliterate black and white squares. Evidently spreading capacity, while it varies with different pigments, will also depend on the dilution with oil and turps.

It is evident that the purchaser of paint requires a paint which will cover the largest surface effectually, that is, which possesses both spreading capacity and body.

A rough idea of these qualities can be obtained by thinning the paint to a proper working consistency and employing a skilled house-painter to lay on coats over black and white squares, on a board sufficiently large, with a sufficiently small quantity of paint. The weight of paint used and the number of coats required should be noted.

In this way a rough practical conclusion can be arrived at as to the most economical paint to use.

If, for instance, zinc white and white lead be compared in this way, the zinc white will be found to spread further, and moreover, weight for weight of pigment used to cover as well as white lead, but each coat laid is more translucent and more coats are required.

The question, therefore, in practice becomes a somewhat complex question of cost of pigment and cost of labour, and is still further complicated by the medium used to prepare the pigment and the way it is used. It is, for instance, becoming a common practice to lay in the ground paint with lithopone, which is a good body colour, and then finish with a zinc white enamel. While therefore the experience of the trade over large jobs soon arrives at definite conclusions, it is difficult to devise sound laboratory methods for determining body and spreading capacity.

The most important quality required by the purchaser is durability.

This can be only tested by time experiments under different conditions. Elaborate experiments have been made by the Educational Bureaus of the Paint

Manufacturers' Association of the United States on this question.

The climatic conditions are, however, so different that a systematic research, in which paint manufacturers, scientific chemists, and some Government Department like the Office of Works should collaborate, are urgently needed.

Such experiments would make it more possible to lay down definite paint specifications. At present such specifications are of little value as they hardly ever specify the things essential for durability. For instance, it is of little use to specify that a white enamel shall be made up of a zinc white of a certain standard of purity, when the durability of the enamel depends on the oils and varnishes it contains and their method of manufacture.

It would be far better in the case of all Government and municipal contracts to state the purposes for which the paint is required, and insist on the composition of the paint being given in the specification.

Experiments on the impermeability to moisture of paint films will be found described in *Paint Technology and Tests*, by Gardner.

It still remains to be seen how far these measurements bear on the behaviour of a paint film in practice.

The author introduced a method of testing varnish films painted out on glass which could even be applied to enamels by finding what pressure was necessary to scratch through a film with a blunt steel point, but the method though yielding interesting results has not been adopted.

The whole question is waiting for systematic and organised research.

Most exhaustive experiments have been carried out for many years in America on the durability of paints. The accumulated literature is so large that it can only be referred to here.

Certain very important conclusions have, however, been arrived at.

It is evident that a paint should be regarded as an aggregate of pigment particles mixed with a cementing medium, and that the durability of the coating depends largely on the proper grading of this aggregate, and that consequently mixtures of pigments are more durable than pure pigments. For instance, the most durable white paint for external use should contain about 60 per cent. white lead, 30 per cent. zinc white, and 10 per cent. barytes.

For the protection of iron and steel, there is considerable evidence in favour of using highly oxidised paints like red lead and basic chromates.

Wall Paper.

Wall papers are either printed with suitable pigments mixed with size or are dyed right through the mass by adding a suitable dye or pigment to the pulp.

The only question of interest to the architect apart from their artistic merits is the permanency of the dyes or pigments used.

This is easily tested by exposure to light in a south window for a fortnight, the sample being cut in half, and one half kept in a drawer while the other half is exposed.

Many of the coal-tar dyes, which are now very largely used both for printing on paper after making into suitable pigments by being thrown down on a suitable base, and for staining the paper-pulp, are quite sufficiently permanent for all practical purposes, while others are very fugitive. There is no reason, therefore, why the paper stainer should not make a selection of suitable dyes of sufficient permanency. The colours should stand a fortnight's exposure with very little or no change, and any change which does take place should be in the direction of a pleasant mellowing of tint.

Stockholm Tar.

This is obtained by the distillation of resinous pine wood, and contains both resin and turpentine. Its specific gravity is 1·04. On heating it loses water, acetic acid, and turpentine, leaving as a residue Stockholm pitch.

Coal-Tar Pitch.

This is the residue left after the distillation from coal-tar of the more volatile constituents. It has a specific gravity between 1·09 and 1·12.

In testing pitch it is usual to determine—

(1) The softening point, that is the temperature at which the pitch can be twisted two or three times without breaking.

(2) The melting point.

(3) The percentage of free carbon, that is the residue left after extraction with toluol.

(4) The loss by evaporation at 329° F. during seven hours.

A standard coal-tar pitch gave, according to S. S. Sadtler:—

Specific gravity	1·29
Softening point	106·8 F.
Melting point	141·8 F.
Loss by evaporation	2·51 per cent.
Percentage of free carbon	28·81 ,,

Creosote Oil.

Creosote oils, differing in composition from each other, but all having valuable preservative and antiseptic properties, are obtained during the destructive distillation of wood and coal, and from blast furnace gases.

Creosote oil from coal is used for preserving timber, and contains phenol, cresols, naphthalen, and other hydrocarbons, pyridin, quinolin, etc.

Various specifications have been adopted from time to time for this material.

The Midland Railway specification, for instance, requires not less than 61 per cent. of tar acids, and not less than 25 per cent. distilling at 600° F. and a specific gravity of 1·04 to 1·008 at 90° F.

Considerable doubt exists as to what are the most valuable preservative constituents, the examination of old creosoted timber having shown that the tar acids, formerly regarded as very important, had almost disappeared, while the naphthalene which it was supposed would volatilise was still present.

Apparently light oils boiling below 205° disappear, but the heavy oils remain indefinitely. The Forest Service United States have also given preference to the heavy oil of high boiling point, as having most value. The German standard requires no distillate up to 150° C. and 25 per cent. as a minimum between 150° C. to 235° C.

Knotting.

Knotting which is used by painters to cover the knot in wood before painting is essentially a shellac varnish made with naphtha.

Red lead ground in size followed by red lead ground in oil is sometimes used.

Paste.

Paste is prepared from white wheat flour, the flour being first worked up stiff with cold water, and then boiling water added with vigorous stirring. A little alum is sometimes added, or powdered rosin, heating and stirring till the rosin is incorporated, and finish with a thin solution of gum arabic. (*Building Construction*, Longmans, Green & Co.)

Willesden Fabrics.

The Willesden process is a method of water-proofing a fabric by treating with a solution containing copper and ammonia compounds, by which the cellulose is partially dissolved, thus resulting ultimately in a waterproofing cupro-cellulose varnish.

Putty.

Putty is a stiff paste of whitening in linseed oil. For special purposes, white lead is added, or a red lead putty may be used.

Glue and Size.

Glue and size are similar products obtained from bones, or from the portions of hides rejected by tanners in the preliminary operations of tanning. The material is washed and cooked with water and the resulting solution evaporated and cast into moulds. The cold jelly is then cut into any desired shape and dried. The dried glue is sold either in the original cakes or is ground and sold as a more or less fine powder. In general the glue and size made from hide pieces are of higher quality than those made from bones. Bone glues and sizes are distinguished by a characteristic odour, show in most cases a pronounced acid reaction, and in general do not give so strong a jelly when dissolved in hot water and cooled as is given by the hide products.

Glue.

Before being melted for use glue should be soaked in water till soft, and then melted on the water-bath. The same brand of glue, if of uniform strength, should always be used at the same concentration. Weak glues should be used in the proportion of one part of glue to one of water, while glues giving a strong jelly may be used in the proportion of one part of glue to two parts of water. Melted glue should on no account be overheated. It is better not to heat it over 185° F. (85° C.), and only so much as is required for the next day's work should be prepared at once.

A good skin glue should satisfy the following tests:—

(*a*) It should contain 13 to 18 per cent. of moisture as determined by drying at 105° C. The cakes should not be brittle or pliable, or the powder cake into a solid if left standing at room temperature.

(*b*) It should give a firm jelly after being soaked in tap water overnight.

(*c*) A 10 per cent. jelly made with it should be moderately firm to firm when cold at ordinary temperatures (56° F., 13° C.), and should remain sweet if kept two days.

(*d*) The glue should be nearly neutral to litmus.

A good bone glue should satisfy tests (*a*) and (*b*), but the jelly formed after soaking will be much less firm. It should not, however, dissolve or form a very slimy mass except at high temperatures. In test (*c*) the jelly given by a good bone glue will be soft to moderately firm.

Size.

Size is sold either as a jelly or in powder as concentrated size. Many sizes on the market contain considerable quantities of alum either dissolved in the jelly or present in the concentrated size in the form of easily distinguishable white crystals.

Alum acts as a useful preservative, but gives a fictitious value to the strength of the jelly. The acidity due to the alum may injuriously affect delicate colouring matters.

A good skin size should satisfy the following tests:—

(*a*) It should give a moderately firm jelly in 10 per cent. solution when cold (56° F. 13° C.).

The percentage of air-dry glue in tub size may be determined for the purpose of this test by drying at 105° C. and allowing for 15 per cent. moisture in the air-dry glue.

(*b*) It should have no objectionable smell.

(*c*) If it contains no alum it should be nearly neutral to litmus.

A good bone size being weaker should give a soft jelly in 15 per cent. solution under the conditions of test (*a*), and this jelly should satisfy test (*b*).

Asphalt.

Asphalt is the name given to a compact form of bitumen.

Asphalt is found in various localities, more or less impregnated with mineral matter, and passing from a nearly pure solid bitumen to a rock impregnated asphalt.

The best known localities are the Dead Sea, the district near Babylon, the Pitch Lake in Trinidad, Val-de-Travers in Switzerland, and the asphalts at Seyssel in France. In addition various deposits are found in the United States.

Albertite occurring in New Brunswick, and Grahamite in West Virginia, and Gibsonite in Utah, are bitumenous substances which differ in their chemical properties from true asphalts and are used for water-proofing purposes. In addition many asphalts impregnated with rocks and sands occur in the United States.

As has been already stated every stage exists between a pure asphalt and a rock impregnated with asphalt, thus requiring different treatment before the material can be used for paving.

As an example of a rock impregnated asphalt Val-de-Travers can be taken. This is a limestone containing from 7 per cent. to 20 per cent. of bitumen. Before it can be used artificial bitumen must be added to it to make it sufficiently fusible. The resulting product is called an "asphaltic mastic."

The Trinidad Lake asphalt contains about 30 per cent. to 40 per cent. of clay and silica. There are also pure bitumens and malthenes containing little mineral matter.

Bitumens are used for various purposes.

(1) Dissolved in volatile solvents they can be used as varnishes for iron work, etc., and appear in commerce under various names; they are constituents of Black Japan.

(2) Mixed with fibrous materials they form roofing felts.

(3) Used as damp courses and to lay over the whole foundations of a house.

(4) For laying asphalt roofs and pavements.

The conditions that have to be met in order to obtain a satisfactory asphalt pavement are as follows:—The asphalt selected must not flow at the highest temperature it will be subjected to, or crack at the lowest. In preparing the asphalt mastic the bitumenous flux added should not lose much in weight when heated to 325° F.—400° F., as otherwise during melting and laying of the asphalt mastic the composition will change considerably. It should therefore not flash below 325° F., and should not lose more than 5 per cent. when heated to 325° for seven hours. The best fluxes are those obtained from petroleum residues. The asphalt apart from the mineral matter should be soluble in carbon bisulphide up to 95 per cent., and in 87° Baume mineral naphthas not less than 65 per cent. and not more than 80 per cent.

Penetration Test.

In order to decide whether the asphalt mastic is neither too hard nor too soft, it is warmed up to 78° F., and a weighted needle attached to a scale is allowed one second to penetrate and the depth of penetration recorded. A good mastic will give a reading between 70° and 80° on the Bowen penetration machine. Further information can be obtained by testing the penetration at different temperatures.

The asphalt when laid is a mixture of bitumen with a certain percentage of mineral matter in a very fine state of division known as the filler, and a certain percentage of sand. The best material for the filler is either limestone or Portland cement. Val-de-Travers is already impregnated with limestone.

In other cases finely powdered limestone may require to be added.

Very elaborate experiments and tests of pavements carried out over many years by Clifford Richardson (*The Asphalt Pavement*, by Clifford Richardson) has resulted in the selection of a certain proportion of filler and sand, and a certain grading of sand as the best. In making asphalt roofs it will be found that the only suitable foundation for the asphalt is concrete. The asphalt is laid in two coats, a softer one beneath and a harder above. It is probably sufficient to dispense with the under coat and paint over the concrete with an asphalt dissolved in benzene. The same care should be taken in the selection of the asphalt, flux, filler, and sand, as is necessary for paving.

A properly laid asphalt roof is excellent for roof-gardens and playgrounds where it is subjected to constant traffic.

The following table, which is quoted from Richardson on *Asphalt Pavements*, shows the best aggregate in the proper percentage for making an asphalt surface:—

Asphalt Surface Mixture.

			Mesh of Sieves in Number of Holes to the inch.	
Correct surface mixture 100%	Bitumen 10·5%			
	Mineral aggregate 89·5%	Filler and Sand passing 200 mesh 13%		
		Sand 76·5%	100·13%	26%
			80·13%	
			50%	23·5%
			40%	11·0%
			30·8%	16%
			20·5%	
			10·3%	

An excellent waterproof concrete can be made by replacing Portland cement by asphalt.

The following is a good mixture for this purpose :—

		Per cent.
Mineral aggregate	Bitumen	7·4
	Passing 200 mesh . .	5·2
	,, 10 ,, . .	29·4
	,, 8 ,, . .	2·2
	,, ¼-in. sieve . .	3·5
	,, ½-in. ,, . .	9·8
	,, 1-in. ,, . .	33·5
	Retained on 1-in. sieve .	9·0
		100·0

Voids in mineral aggregate, 13·2 per cent.

Roofing Felts.

These are mixtures of tar or asphalt with some fibre such as jute, cotton, wool, or asbestos.

There seems to be a consensus of opinion among engineers that of these fibres jute is the most unsatisfactory, and that the introduction of a certain percentage of wool much improves the material.

A high class asphalt should be used which will pass the tests for asphalts already laid down to impregnate the fibres.

The felt should contain at least 50 per cent. of asphalt, and should be able to stand a tensile test of 30 lb. per inch of width.

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